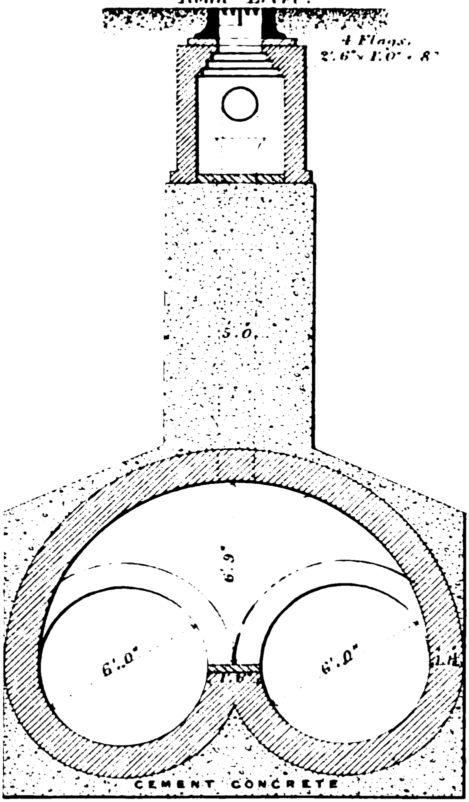
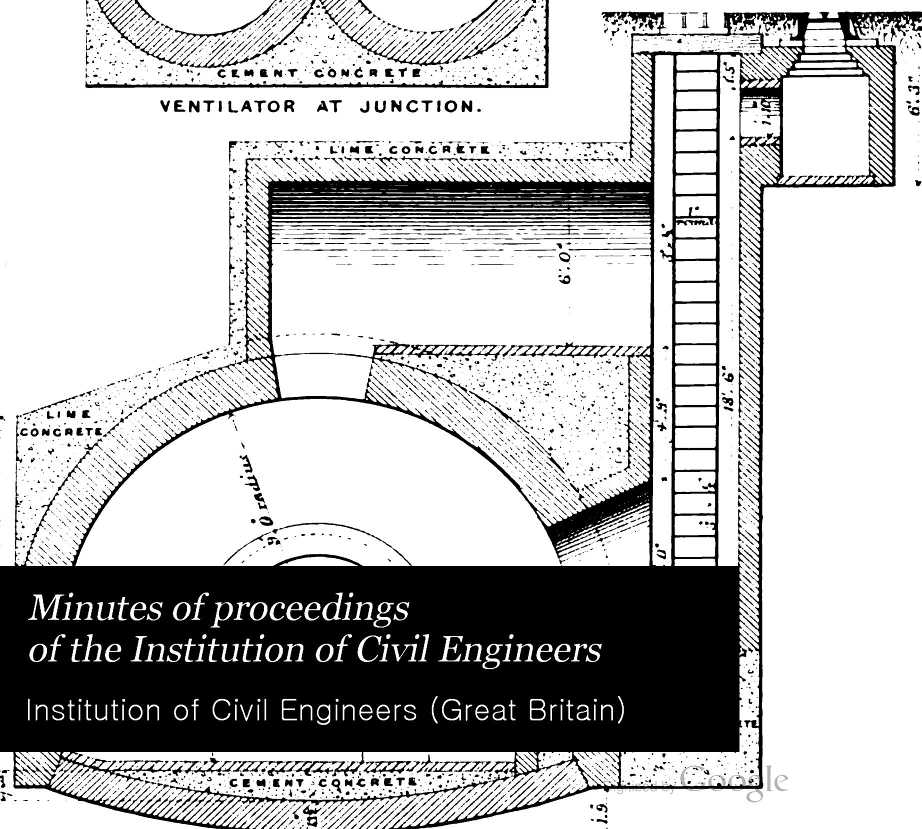


VENTILATOR AT JUNCTION.

Fig: 8.



Minutes of proceedings of the Institution of Civil Engineers

Institution of Civil Engineers (Great Britain)

MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. XLIII.

SESSION 1875-6.—PART I.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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CONTENTS.

SECT. I.—MINUTES OF PROCEEDINGS.

November 9, 1875.

November 16, 23 *and* 30, 1875.

December 7 *and* 14, 1875.

December 21, 1875.

SECT II.—OTHER SELECTED PAPERS.

SECT. III.—ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

ERRATA.

Vol. xl., p. 249, line 26 from bottom, for "circulating" read "reciprocating."
„ xlii., p. 304, line 11, for "£43,000" read "£35,833."
„ „ p. 360, line 3 from bottom, for "quantity of iron produced" read "iron ore produced."
„ „ p. 363, line 17 from bottom, for "200,000,000 tons" read "95,000 tons."
„ „ p. 363, line 15 „ for "190,000,000 tons" read "85,800 tons."
„ „ p. 363, line 12 „ for "2,600,000,000 tons" read "1,110,000 tons."
„ „ p. 363, line 10 „ for "25,000,000 tons" read "11,250 tons."

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1875-76.—PART I.

SECT. I.—MINUTES OF PROCEEDINGS.

November 9, 1875.

THOS. E. HARRISON, President,
in the Chair.

No. 1,447.—"The Manora Breakwater, Kurrachee." By WILLIAM HENRY PRICE, M. Inst. C.E.

1. SKETCH OF KURRACHEE HARBOUR WORKS. (Plate 1.)

THE harbour of Kurrachee is situated on the north border of the Arabian Sea, 51 miles west of the principal mouth of the river Indus. It is the natural port of Sind and of the Punjâb, bearing much the same relation to those provinces and to the Indus that Alexandria does to Egypt and the Nile, and is 500 miles from the nearest port on either side. The sea-bottom off Kurrachee shelves rapidly, not being sensibly affected by deposit from the Indus, the drift of which, under the action of the prevailing winds, is in the opposite direction, towards the Gulf of Cutch. Kurrachee harbour is essentially a backwater, as the only river opening into it—the Layari—never flows for more than a few days in each year. The area of the backwater at high tide is 18 square miles, a portion of which, however, is not freely open to the tidal flow. The range of tide is 7½ feet at mean springs; at extraordinary springs it is sometimes 12 feet.

Manora Point is a headland 90 feet high above mean sea-level; it consists of a capping of conglomerate, resting on clay. The clay has been undermined by the sea, and the rock has in the lapse of ages fallen in great masses, which, for about 700 feet from the shore, in a depth of water of from 10 to 25 feet, crop up thickly from the sandy bottom in irregular forms. For the remainder of the length of the breakwater, in a depth of water of 4 or 5 fathoms, a few boulders

KURR

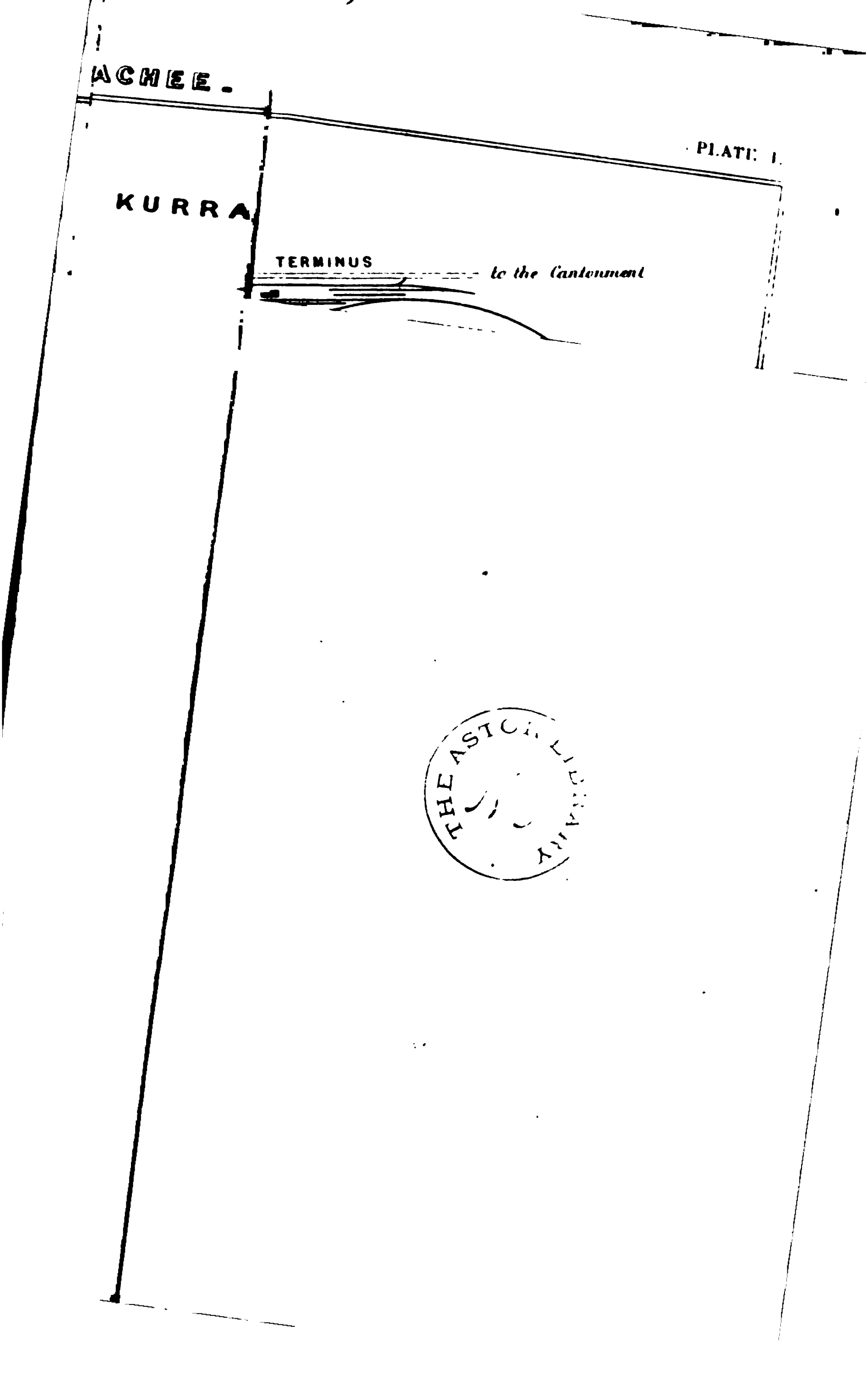
rise here and there above the sand. Clay occurs at a d
8 to 14 feet below the surface of the sand.

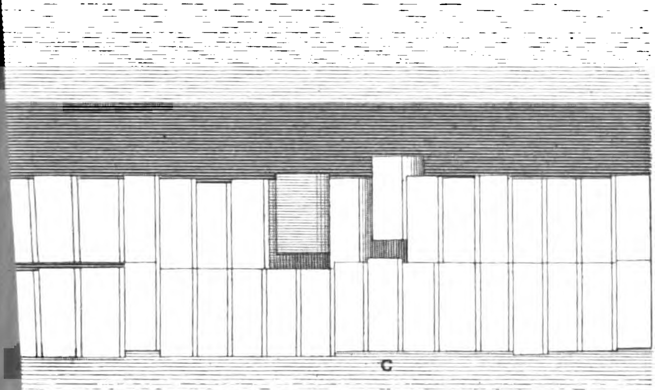
Up to about twenty years ago, the difficulties rendered the harbour unfit for any except native though some improvements were effected, the gene was left in abeyance until 1856, when, at the instiga (now the Right Honourable Sir) Bartle Frere, then C in Sind, a reference was made to the late Mr. Jam Past-President Inst. C.E., who sketched out the ma of his final plan, and in 1858, aided by Mr. Will M. Inst. C.E., prepared a design for the deepeni bar and the general improvement of the harbour, also the sites for docks, basins, and quays. Sanction first instance, confined to works bearing on scour; but ponement of the breakwater directly checked the full b the other works, and was indirectly injurious, giving a apparent support to objections raised during their prog caused great delay.

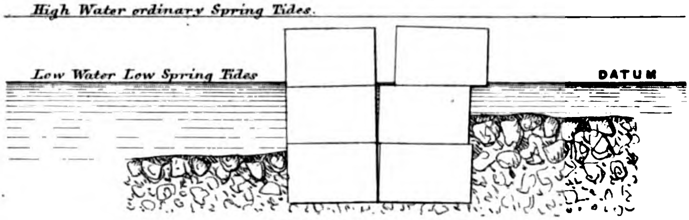
The works were commenced in 1860, and were carri 1874 under the superintendence of the Author, excepti years, 1864–5, during which Lieutenant (now Major) M R.E., Assoc. Inst. C.E., held charge. Up to 1865 the ge trol was in the hands of the superior officers of the Pub Department. From 1866 to 1868, the undertaking was though the staff continued surveys and observations; were resumed in 1869, and from 1868 to 1873, Mr. Park Consulting Engineer, the conduct of operations still r however, in the Public Works Department.

The chief works besides the breakwater are: a ston 8,900 feet in length along the east side of the lower dredging on the bar to assist the tidal scour; the excava rocky obstruction (Deep Water Point) on the west sid lower harbour; the formation of a channel 2½ miles long the upper harbour, for the passage of native craft and and for the collection of tidal waters; a jetty 1,400 feet i faced with masonry wharf walls, to which access is aff the channel just mentioned; an iron screw-pile bridge 1, long, over an opening in the Napier Mole, to tap the ea water; and an embankment 2,780 feet long, to close the " Creek," a secondary entrance to the harbour. Of the wo breakwater is the only one of which the construction wou to present special interest as viewed from the standp European practice.

PLATE I.







CROSS SECTION AT C.

NEAR THE END.

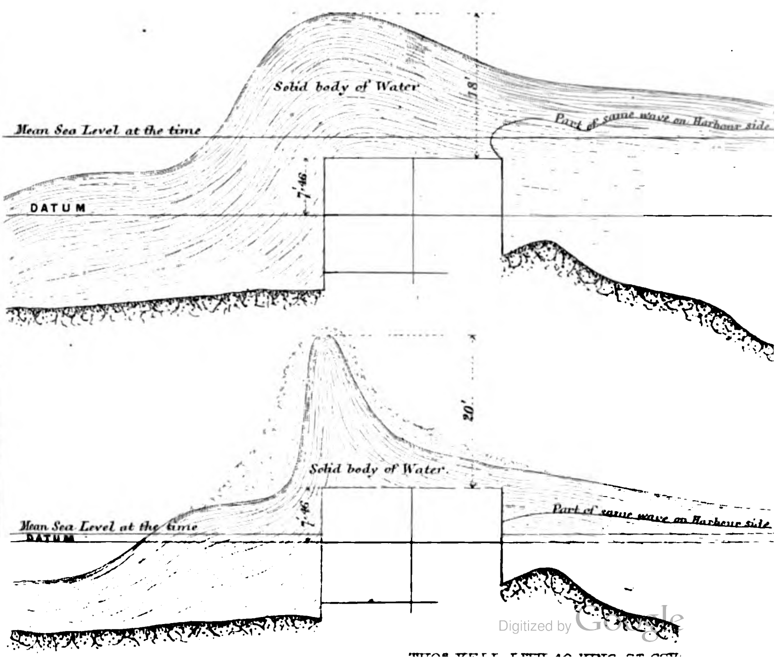
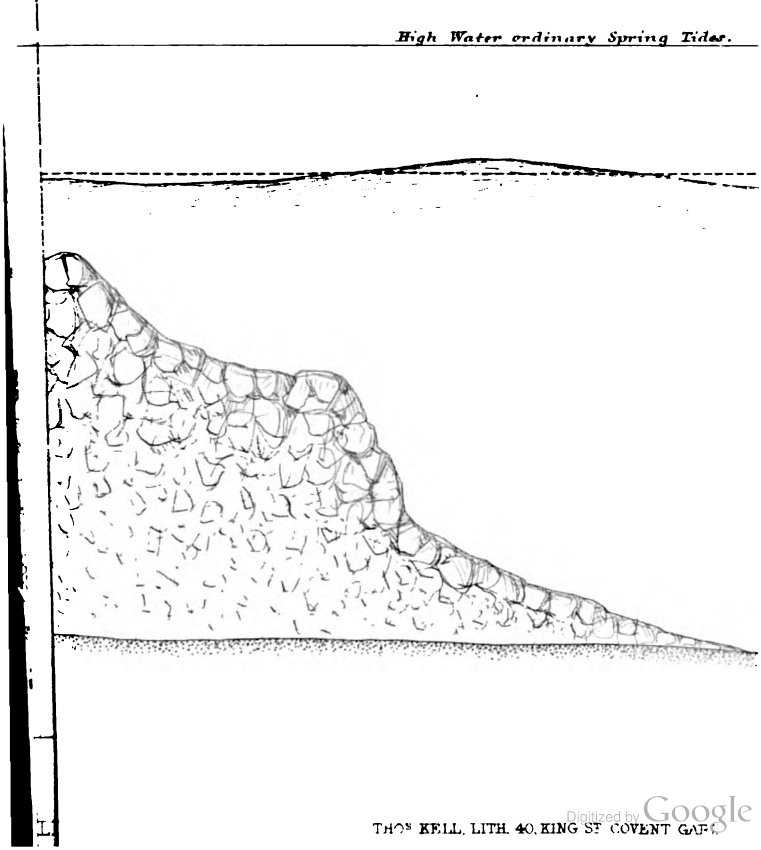
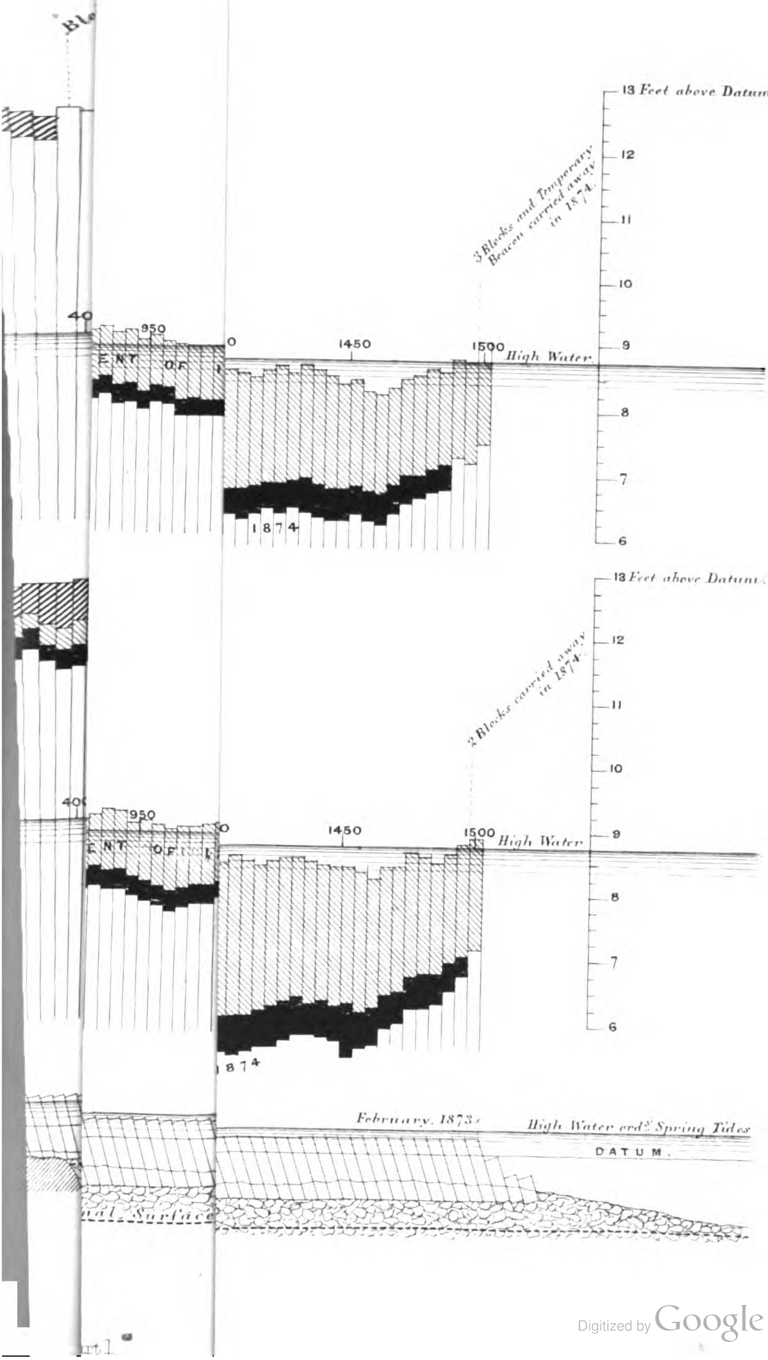


PLATE 3.



THOs KELL, LITH. 40, KING St COVENT GARD.

PLATE 4.


13 Feet above Datum
12
11
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9
8
7
6
3 Blocks and Temporary Beacon carried away in 1874.
950
1450
1500
High Water
1874
13 Feet above Datum.
2 Blocks carried away in 1874.
High Water
February, 1873.
High Water ord? Spring Tides
DATUM.

The immediate results, so far, may be briefly summarised as follows:—A new direct entrance channel, 6 feet deeper than the old circuitous one, has been formed to a depth of 20 feet at low water. This, with the breakwater, trebles the former capabilities of the entrance during the south-west monsoon season, and doubles them in the fair season; renders the harbour accessible to vessels of the largest class; greatly saves the use of steam-tugs, and allows of the regular arrival and departure of the mail steamers. The breakwater, also, enables native craft to use the port at all seasons.

The capacity of the harbour anchorage has been increased nearly threefold for vessels of moderate size; and though limited for very large vessels, capabilities exist for its extension by dredging at a moderate cost. In the upper harbour, the lighters and native sea-going craft have been much benefited by the jetty, and the formation of a channel leading to it by the scour of the diverted Chinna Creek waters. Eastward above the jetty, the channel, 1 mile in length, will serve for the extension of wharfage, for tapping the east backwater, and for maintaining deep water alongside the jetty.

The breakwater forming the special subject of this communication cost rather less than £100,000, but a gross sum of about £450,000 has been expended on the improvements, the value of which will be still more felt when through railway communication with the Punjâb and the North-Western Provinces is completed. As it is, the trade which in 1843, when Sind came under British rule, was of an annual value of £116,052, is now worth about £3,500,000 per annum.

2. Design of the Breakwater.

The breakwater extends from Manora Point, on the west side of the entrance of Kurrachee Harbour, in a south by east ¼ east direction, for a length of 1,503 feet, terminating in a depth of 5 fathoms at low water. Its object was, mainly, to shelter the entrance from the violent and dangerous seas of the south-west monsoon, and at the same time to break them so as to prevent their tearing up sand from the bottom to deposit it as a bar.

The characteristics of the locality, as to sea and weather, which influenced the design, may be briefly described as follows:—Storms are unknown at Kurrachee[1], which is north of the limit

[1] The greatest velocity of wind at Manora, since 1870, was 62 miles an hour, in a squall from N.N.E., lasting one hour, on the 26th of September, 1872. It was of exceptional violence for Kurrachee.

of cyclones; but the south-west monsoon brings a very heavy sea, lasting with full force for about three months, from the middle of June to the middle of September. During this period rain only falls for a few days. From the middle of October to the middle of February strong easterly winds blow occasionally, but do not bring a heavy sea. The intervals between the south-west monsoon and the fair season proper are subject to occasional strong breezes and squalls, raising a sea which is sufficient to interrupt the progress of sea works, though not formidable as regards navigation. The wind during the south-west monsoon is not usually more than a strong breeze;[1] but at that season the local wind has little influence on the force of the sea, which has a fetch of 500 miles; a depth of 100 fathoms is found within 77 miles of the harbour. At this time the waves in the deep water at the head of the breakwater vary from 3 to 15 feet in height from hollow to crest, and from 300 to 600 feet apart, moving at the rate of about 15 to 30 nautical miles per hour. Of the high waves, about three-fourths of the elevation is above, and the remainder below, the mean sea-level at the time. Though called the south-west monsoon, the wind is generally west; but the run of the wave is more southerly than the wind, being usually from south-west by west, so that it meets the breakwater at an angle of 70°. These relative directions of the waves and the breakwater have an important bearing on the stability of the work.

As regards tidal currents, the consideration chiefly affecting the design was the desirability of limiting the length, to avoid, as far as practicable, diverting the flood tide, which makes from the westward, to a more circuitous course in entering the harbour. The strength of tide was not such as materially to affect the work of construction, the flood setting across at the rate of 2 miles an hour at springs; while the ebb, being parallel to the breakwater, was scarcely felt.

3. General Construction. (Plates 2, 3, 4.)

The mode of construction adopted is believed to be novel, at least, as a whole. The base is a bank of rubble stone thrown in upon the natural bottom, chiefly from boats by hand, and levelled off, for the most part, to 15 feet below low water, but near the shore, where the original depth is less than this, to 10 feet. Upon this base a superstructure is raised, consisting, with the exception of some

[1] Unusual weather occurred at the end of July 1874, in the middle of the south-west monsoon, the particulars of which are given at page 15.

smaller blocks used in special positions near the shore, of concrete blocks, each 12 feet by 8 feet by 4½ feet, of 27 tons weight, set on edge without bond; so that an end view presents six blocks, two forming the width, and three the height. This makes a solid vertical wall, of which the width and depth are alike 24 feet. The blocks were laid with an inclination towards the shore of 3 inches to 1 foot to insure the stability of the end during the progress of the work. This plan enabled each block to fall into place easily, and helped to obviate distortion from slight errors or subsidence of the foundation. The inclination also secured the upper blocks against displacement by lifting, and proved of great service by causing the tiers to tighten together under the action of the sea. The bottom of the lowest course of blocks was shaped so as to set level on the rubble base. For 108 feet from the shore the breakwater is levelled off on the top with concrete to 4 feet above high water of spring tides, to which latter level it was gradually dropped in the next 468 feet, and so continued to the end; but it has since settled, more or less, in the middle and outer portions as much as 3 feet. Between 108 and 1,180 feet from the shore the heads of the top blocks were left square, so as to form a jagged top, which, it was thought, would afford a better bond for a concrete capping if required. For the outer 323 feet, however, as the top did not then seem likely to require raising, the heads of the upper blocks were made oblique, so as to finish with a level top. In the work executed after the first season, from 270 feet outwards, a stone dowel was inserted between the heel of the top course block and the head of that below. This forms the only connection between the blocks, excepting that a few of the top course near the shore were reset in cement mortar, and a few at the outer end were lately connected by chain ties when refixing the iron beacon, which has been erected on the end as a warning to native craft at high water; the guidance of pilots and the light on Manora Point serving for larger shipping.

4. Rubble Base Work.

The rubble base was formed so as to give at the foundation level a width of about 100 feet, two-thirds on the sea, and one-third on the harbour side of the centre line. The outer end was extended 60 feet beyond the superstructure, and fanned towards the harbour, to guard against flood-tide scour. At first the rubble, to about one-half the length, was deposited in a ridge up to low water, in the belief that the sea during the next monsoon would lower it to

about 12 feet. It was not, however, lowered more than from 7 to 9 feet; but, to provide against greater effect in deeper water or on more obstruction, the foundation was carried as low as the irregularities of the bottom admitted, until the full proposed depth of 15 feet at low water was reached. The clearance of the foundation for the first season's work was consequently heavy, the more so through the rubble having become clogged by sand and shell-fish; but during the second season progress was aided by using a steam dredger to excavate the high bank. Want of funds caused the deposit of the outer half-length of the base to be postponed to the season during which it was built upon, and the result was considerable settlement, though without dislocation of the superstructure. This portion was formed so as to leave only a depth of about 2 feet to be excavated by the divers; and it would, no doubt, have been throughout an advantage to have left a top layer of 1 foot or 2 feet to be put on during the season of building, in which the foundation bed could with ease have been formed.

5. Diving Work.

The divers were employed chiefly in levelling the foundation bed; they also saw to the proper setting of the blocks below water, and disengaged the lewises. They used Siebe's helmet-dress apparatus, and worked from a boat ahead of the superstructure.

Two European mason divers were employed during the first two seasons, but during the last season only one. These were aided by native divers trained on the work, of whom six were employed when it was in regular progress. The party was divided into three shifts of three hours, each consisting of one European and two native divers, excepting in the last season, when one of the shifts was worked by natives only, at excavating the rubble. When there were two Europeans, each made by turns two shifts one day and one the next; but during the last season the one European diver made two shifts daily—no small effort in an Indian climate. The natives, as a rule, worked only one shift each daily. When not diving, the Europeans were generally employed in repairing the dresses, which required much attention.

The divers excavated the rubble generally about 2 feet, though for the first season their work was exceptionally heavy. For shifting the rubble, iron basket skips were worked by hand crabs from outriggers on the outer end of the Titan, and when filled by the divers, were hoisted and discharged alongside the superstructure, chiefly on the harbour side. When blocks were being set the divers were always withdrawn in their boat out of danger.

from accident in the lowering. The diving work was throughout free from accident, though the Europeans had no easy task in working with and watching the untrained natives. Excepting the sickness latterly of one of the Europeans, which was not ascribable to the nature of his work, the divers enjoyed good health. The diving party was throughout rather weak in number of skilled men, dependence on local resources having been urged too far, though, fortunately, the strain did not seriously tell upon the work.

6. Concrete Block-making.

The practicability of obtaining hard stone of sufficient size for the more exposed portions of the superstructure was considered, but after an extended search by Lieut. Merewether, R.E., it was decided to use concrete blocks throughout. The question then arose as to the comparative merits of artificial hydraulic lime made on the spot, and Portland cement imported from England. After careful experiments by the above-named officer, this was settled in favour of the cement, on duly balancing strength and cost; though at a distance from the seaboard, or with cheaper materials for the lime, the latter would have had the advantage. The composition for one block of 16 cubic yards, weighing 27 tons, was for the most part as follows:—

	Cubic feet.
Portland cement,[1] 9¼ casks, of which the weight (at Kurrachee) was 3,729 lbs., and the bulk	44
Sand (gravelly), from the bed of the Layari	180
Shingle, from the Manora conglomerate quarry	252
Quarry lumps from the same, 14 to 28 lbs. each	144

The ratio of the bulk of the cement as it left England to that of the finished block was about $\frac{1}{11}$, and that of the bulk of the same cement in India about $\frac{1}{10}$, the difference arising from absorption of moisture in transit and in storage.

Salt water was used for the mixing, ordinarily 432 gallons to each block, but increased in hot and dry weather by about 10 per cent.

In the earlier blocks (about one-fifth of the whole) 50 per cent. more cement was used. The reduction is believed to have been carried to the utmost extent consistent with the soundness of the blocks, which was aided by the excellence of the sand (a mixture of various sizes), by the 'key' of the conglomerate lumps, and by the large shingle being rough in parts with natural cement.

[1] This refers to the heavy cement, which weighed in England 118 to 120 lbs. to the bushel, and which is taken as the standard. The proportion of cement was regulated by weight, after having been fixed in relation to bulk.

The cement was supplied by Messrs. Knight, Bevan and Sturge, the Wouldham Company, and Messrs. J. B. White and Brothers. The heaviest (as shipped) was 118 to 120 lbs. to the bushel, and the lightest 104 to 108 lbs. The weights used of each per block were the same, and the cost thus varied but slightly. All three made excellent work, the lighter cement having somewhat the advantage in quick setting, but the heavier, after a time, in hardness. Ordinary fir casks were employed for packing, and the percentage of damage and loss on the voyage and in keeping in India was insignificant. About 3,500 tons of cement were used in the breakwater, at a cost of from £3 17*s.* 6*d.* to £4 10*s.* per ton in 1870–71; the variation of cost was chiefly in rates of freight. The cements all increased slightly in weight and bulk (mostly in the latter) on the voyage and in keeping in India, owing, no doubt, to the absorption of moisture. The lightest cement increased most in weight and the heaviest in bulk, so that the specific gravities were from 1⅓ to 9¾ per cent. less than at shipment. The seasoning thus indicated was probably beneficial—by slaking minute particles of quicklime—though making the cements rather slower in setting.

The mixing-station and block-ground (the latter reclaimed from the sea) were on the inner side of Manora Point, ½ mile from the breakwater. Four 'Messent' mixers were erected against the berm of the cliff; they were worked by an 8-HP. engine, and were very efficient. It was seldom necessary to use more than three, which number sufficed to make 1⅓ block per hour. The mixers and engine, as well as the other special plant, were supplied by Messrs. Stothert and Pitt, of Bath. The cement, sand, and shingle were brought along the upper railway line in wagons, and, having been measured on the platform, were shovelled into the mixer hoppers. From the mixers the concrete was discharged into wooden skips, each holding ½ cubic yard. The skips were conveyed on trucks to the block-ground, and were tilted into the moulds by hand travellers, of which four ran on the Goliath rails, the quarry lumps being at the same time incorporated. The blocks were moulded on a platform of concrete and rubble masonry adapted to the slope in which they were to be set, and to the lift of the Goliath. They were ranged in six rows, three on each side of the main railway line, and leaning towards the latter, for economy of space. The platform was 1,200 feet in length, and held five hundred blocks. The blocks were chamfered 3 inches all round, and panelled 13 inches wide and ¾ inch deep along the front and back edges at the top and bottom (except the bottom of the lowest course) so as to facilitate

close setting. The moulds were of 3-inch pine planking, tied with iron straps, and with five bolts (slightly tapered) running through. These bolts were drawn out six hours after the block was made, and the moulds were removed after eighteen hours. The two oblong holes for the lewises were formed by moulds of cast iron or wood, and were recessed at the bottom by inverted wooden cups slotted so as to admit the lewis head. The lewis moulds were lifted a little and dropped again into their places, after four hours, and were finally removed after twelve hours. The blocks were watered for a week after being made, so as to keep them moist for equal and proper setting under the Indian sun. The quality of the blocks proved in every way satisfactory under severe tests; they were sometimes set in one month after being made, and on one occasion within ten days; a block was safely lifted as an experiment seven days after being made. The period of one month, or even somewhat less, might usually have sufficed for the two lower courses, though with a liability to flushing in transit, but not for the upper blocks, which had to bear the weight of the Titan near their ends; and, in fact, a few of the blocks, six weeks to two months old, cracked from this cause during the last season's setting. The number of blocks made was one thousand six hundred and forty-seven of 16 cubic yards or 27 tons each, two hundred and eighteen of sizes varying from 15 to 10 cubic yards each, and one hundred and seven of 2 cubic yards each.

7. Block-setting. (Plate 3.)

The attachment for lifting the blocks was by two lewises 6 feet apart, passing vertically through, and catching by their ⊥ ends, after a quarter turn, in the wooden cup recesses. The blocks were lifted by the 'Goliath,' a steam hydraulic travelling crane, the span of which was 50 feet, the traverse of the crab 40 feet, and the lift 3 feet 2 inches. The power was supplied by an 8-HP. engine. The trucks, ten in number, carried each one block, standing on edge at its proper slope, but in length parallel to the railway, which was of the 5½-feet gauge. The loaded trucks were taken separately by a tank locomotive to the breakwater. The blocks were set by a crane called the 'Titan' (Plate 3), devised in consultation between Mr. Parkes and the Author, and made by Messrs. Stothert and Pitt, of Bath. The Titan overhung the end so as to carry the blocks of three tiers in advance to their places; it was capable of carrying a weight of 27 tons 26½ feet longitudinally, and 12 feet transversely, and of lowering

and raising it vertically within the limits of the chain. Of the longitudinal travel a length of 22 feet was in advance of the side frames. The whole machine, when not loaded, could also move forward or backward. On the top was a traveller and crab to handle the blocks, all the motions being controlled by one man.

To assist in balancing, when a block was run far out, the Titan was tied down by chains and union-screws to lewises, let into the blocks already set; and the side frames were also blocked up in front. On the top, near the tail-end, stood an 8-HP. single-cylinder engine which drove a horizontal shaft above the platform. This shaft revolved constantly in one direction; all the motions of the traveller and crab were transmitted by bevil-gearing and friction cones, regulated by three levers and a hand-wheel. The Titan was moved by the same engine, but independently of the main shaft.

The method of setting was as follows:—

If a bottom block, on the diver reporting the bed ready, the block, having been slung and lifted from the truck, was let down into the water; the crab was then run out, the block lowered to within 1 foot of its bed, a short distance ahead, and then run back so as to bear hard against the one behind, which steadied and guided it while being finally lowered. The blocks of the second and third courses were also guided into their place by the tier behind. In this way the actual placing required no aid from the divers; but in the case of the blocks under water they reported as to the true setting, and then released the lewises.

For slinging, slewing, and steadying the blocks, laying and shifting the roads, and shunting empty trucks, three masons and twelve labourers were required on the breakwater, and one European engineer and two native firemen on the Titan, all directed by the foreman of masonwork.

During the last working season of ninety-two days, nine hundred and ten blocks were set, containing 14,560 cubic yards, and making a length of 710 feet of breakwater. On some days eighteen blocks, and on one occasion six in an hour and forty minutes were set without special exertion; though such a rate could only be maintained with a calm sea and not too high a tide. The progress of setting was generally limited by the preparation of the foundation and by the supply of blocks.

8. Progress in Execution.

The rubble base was commenced on the 17th of March, 1869.

At the close of the monsoon of the same year a recess was cut in the rock and clay of the cliff to a depth sufficient to 'stable' the Titan; and thence, projecting to 45 feet beyond low-water mark, was formed a 'stump' of concrete blocks moulded *in situ*, on rubble brought up to low water. Plaster of the local gypsum ("cheroli") proved very useful in protecting fresh concrete or masonry from the wash of the sea. The spaces between the blocks were filled in with rubble, and the top capped with concrete to 4 feet above high-water level.

The works generally suffered from suspension under "deficit" orders in 1869–70; but the arrangements were advanced so as to admit of the block-making being commenced in August 1870. On the 1st of November following, the first 27-ton block was deposited by the Titan. Setting then went on steadily—though retarded by the irregular bottom and by the weakness of the diving party—until the middle of February, when interruptions were caused by the sea, which once swept the breakwater clear of all the roads except the length on which the Titan stood. The roads were quickly replaced without loss of material,[1] so that setting was resumed after two days; but was closed for the season on the 4th of March, 1871. The length built during the season was 225 feet, reaching to 270 feet from the shore, with a 'scar' stepping 20 feet farther. Two hundred and seventy-nine large blocks, and sixty smaller blocks used in the stepping down, were set; but, owing to delays of the foundation, the Titan was not worked to its full powers, eleven blocks having been the greatest number deposited in one day during the season.

The second season's building ahead was commenced on the 28th of October, 1871. After a few more boulders had been passed, the foundation was stepped down to the full depth of 15 feet below low water, and the top was lowered to the same extent. Setting was closed (no more blocks being then available owing to want of funds) on the 23rd of February, 1872. A length of 523 feet, besides the usual 'scar,' had been built in less than four months, and the work was now extended to 793 feet from the shore. The great advance on the rate of the previous season was due mainly to improved progress of the foundation work.

On the opening of the third season, the repair of damage incurred during the monsoon and the preparation of the centre road having occupied the month of October, block-setting was resumed on the

[1] In after seasons the railway line along the centre of the breakwater was built in with rubble and concrete, for security during the working season.

1st of November, 1872, and was completed on the 22nd of February, 1873, to the full length of 1,503 feet. The wall had thus been two years and four months under construction, of which rather less than twelve months were actually occupied in setting. The length built during the third season was 710 feet; but this was not the full measure of the powers of the Titan, which were still limited by the progress of the foundation and by the supply of blocks. The end was finished with a 'scar' stepping out 20 feet.

During the working season of 1873–4, the monsoon damage of 1873 was repaired, and a landing-slip for boats was built in the east shore angle. On the 17th of January, 1874, the completion of the breakwater was formally marked by fixing an inscribed "memorial block" in the Titan 'stable.'

9. Action of Sea, Damage, and Repairs.

The characteristic action of the high monsoon waves as they dash over the breakwater is shown in Plate 2. Near the shore the wave is crested with spray, mounting at high water to 35 feet above the superstructure, or nearly 40 feet above the sea-level; while near the outer end the wave rises about one-half as high, but in an almost unbroken mass, until it plunges into the water on the other side. At low water the wave rises to nearly 30 feet above the sea-level throughout, but is greatly broken into spray near the shore, and, near the outer end, is higher though lighter in mass than at high water. At low water, as each wave meets the breakwater obliquely, a marked undulation is reflected to seaward in a corresponding angle, and causes the incoming wave sometimes to break heavily before it reaches the wall. This action takes place in a minor degree at high water. The lap round the extremity forms a secondary wave, which, running up along the harbour side, is gradually reduced (partly by the plunge of the seaward portion), and finally spends itself in the east shore angle. In illustration of the limit of disturbance inside, it may be mentioned that, during the height of the south-west monsoon, open boats have safely approached within 100 feet of the breakwater, up to about 200 feet from the outer end.

The effects of wave-action on the work, and the measures taken to repair the damage, will now be described. (Plate 2.) Shortly after the monsoon of 1871 burst, the centre joint began to open over places where boulders had been met with in the foundation, and by degrees the seaward row beyond 100 feet from the shore overhung more or less, especially at 206 feet, where the

top course projected 2½ feet. The harbour-side row settled more uniformly; but the sea displaced several blocks of the top course —a few of these being at places where the courses below showed little or no settlement. After the monsoon a curious effect was noticed, in the lateral rocking (apparently of the seaward row) of the breakwater near the outer end, under the influence of a moderate swell. The motion, which was at most ¼ inch, and extended from about 100 feet from the shore to the end of the completed breakwater, even over the deep rubble base, would seem ascribable to the action of the wave on the elasticity of the two separate walls forming the breakwater. Slight wear from this action was apparent along the centre joint, but has not since appreciably increased. No grinding of the cross-joints was apparent; on the contrary, the tiers had been packed closer, the sea having, by its oblique stroke, acted especially on the seaward row of blocks, which at the outer end had receded at the top 10 inches behind those of the harbour side, the difference gradually lessening until it disappeared at about 100 feet from the shore.[1]

With one exception none of the Titan-set blocks were completely displaced, but some slight damage occurred to the shore end in the west angle, where the action of the sea was especially violent. The sea drew down the foreshore rubble, as well as three 17-ton concrete blocks which had been tipped on it, and upset one block from position, behind which, however, the concrete capping fell so as to prevent the breach from extending more than halfway across. Out of the 3,000 tons of rubble proposed for this angle, only 500 tons had been put in; but the quantity was made up during the following season at a reduced rate, the saving by which, as well as by other previous changes, more than covered the cost of repairing the damage. The small rubble of the base, which was originally heaped up about 5 feet along each side, was washed down on the sea side, after the first 120 feet, to about 10 feet below low water, or nearly to the foundation level, but was little altered along the harbour side.

On the opening of the season of 1871–2, fourteen of the displaced top blocks on the sea side were reset by the Titan, after the course below had been dressed level transversely. The fallen block of the harbour-side row was replaced by another, and the four blocks ahead of it reset. In other places the centre joint, where unduly open, was filled with concrete. At the close of the season, the gap

[1] In the second and third seasons' work, the difference at the outer end was respectively 6 and 8 inches.

near the shore was built up with small blocks and rubble masonry.

Shortly after the monsoon of 1872 burst, the breakwater being then 793 feet in length, eighteen blocks were washed out from the harbour-side top course in one length of 86 feet, extending from 579 feet to 665 feet from the shore (Plate 2), and the course below partially shifted. At the same place the two upper courses of the seaward row were driven inwards to a curve of 1 foot offset. Seven single blocks also were washed out, three from the first, and four from the second season's work, all from the top course on the harbour side, the next front block in most cases falling back aslant into the vacant place. The shore end only suffered from some battering by the smaller foreshore rubble. It was accordingly determined to deposit about 1,000 tons of conglomerate lumps of 2 tons to 4 tons in weight. Seven 20-ton blocks had been placed, four in a row, on the sea edge of the superstructure to shelter the Titan 'stable'; of these four were upset, and three 'skidded' some feet by the stroke of the sea. On the moving out of the Titan for the working season of 1872-3, the large breach was repaired in seven days by dressing off the partially-shifted second course to low water, packing the space in the centre with large rubble, on the bed thus formed setting a course of fifteen blocks (oblique pattern) and closing the end with rubble and concrete. The single gaps were repaired with rubble and concrete. After the building ahead was completed, twelve blocks of the harbour-side top course, about 200 feet from the shore, were lifted and reset in cement mortar. This experiment seems to have answered well, though only applicable where the work is dry at low water.

During the monsoon of 1873, the first after the completion of the breakwater, damage occurred in four places, all to the harbour-side top course. In two cases a single block was washed out, in one a mass of concrete occupying the space of two blocks, and in one a mass occupying the space of three blocks. In every instance the site of the damage was either identical with, or close to, that of similar damage in previous seasons. This seems clearly to point to weakness of foundation; while in the third season's work on the deep rubble base, where settlement was regular, the centre joint generally became closer during the monsoon. In the working season of 1873-4 these damages were repaired by filling in the gaps with rubble masonry and concrete.

In the monsoon of 1874, the outer end, which had stood the previous monsoon uninjured, lost five blocks, of which two were

from the harbour and one from the sea side of the top course, and two of the second course, forming the upper step of the 'scar.' This occurred at the end of July, the wind having veered to a gale from the south-east, which, on the morning of the 28th of July, reached a maximum velocity of 46 miles an hour. This brought up a very heavy sea from an unusual quarter, against which no special protection had up to that time been given. Excepting the end, the outer half-length suffered no displacement whatever, its settlement having been moderate and regular; but in the shoreward half there was some irregular settlement and further opening of the centre joint.

During the next fair season, 1874–5, one of the harbour-side blocks washed out of the top course was replaced by rubble built *in situ*, so as to square the end; but the others were not replaced. As an aid to secure the end against similar displacement, the six outer tiers of the top course were tied together by chains arranged diagonally and bolted down to each block. Twenty-one of the seaward top-course blocks, where the greatest settlement had occurred, about 300 feet from the shore, were lifted by the Titan and reset in cement mortar, so as to close the centre joint of the top course and correct the overhang to seaward. To effect this operation one block was blown out by powder, so as to release the others, and was replaced by a mass of concrete. The repairs of the season cost £418, and included the re-erection of the iron beacon, which had been carried away with the blocks from the end.

The nature and extent of the settlement during the four monsoons are shown by Plate 4. The settlement may be ascribed partly to the compression of the rubble base, but more to its sinking into the sand below, under the action of the sea; while the irregularity in some parts was caused by boulders in the foundation.

The blocks of the superstructure have not crumbled under the action of the sea or weather, and except at the shore angle, where somewhat battered at first by the small foreshore rubble, they retain their sharp edges and good 'skin,' though encrusted on the top (where below high-water level) with barnacles, and on the sides with limpets. The faces have, however, begun to show signs of the attacks of the "pholas," which burrows to a depth of about 2½ inches. It is found more on the harbour than on the sea side, and mostly on the shore half-length of the breakwater. Its penetration as yet has been only from ½ inch to 1½ inch, and in height its limit is half-tide level. The veneering of the faces with trapstone (which was at one time thought of for the sea-face, but on account

of the expense was not carried out) would, probably, have been a protection against the "pholas," which, however, does not seem likely to prove a formidable enemy to the breakwater, as it does not attack stone of the conglomerate class very freely.

The "teredo" also is found at Kurrachee, but only in wood, which it penetrates freely, especially in the direction of the grain.

Since the deposit, after the first season, of the large stone forming the 'toe,' the rubble base close to the superstructure has shown no tendency to wash down (Plate 2); its present depth below low water on the sea side varies from 6 feet near the shore to 13 feet near the outer end, and on the harbour side it is about 2 feet less. From the wall, however, the berm has been lowered to a flat slope, so that at 50 feet off on the sea side the depth declines gradually from 9 feet near the shore to 22 feet near the outer end, and at 20 feet from the harbour side, from 8 feet near the shore to 17 feet near the outer end. As the foundation is now 10 feet deep at the shore and 18 feet at the outer end, no undermining appears likely. The changes in the base took place chiefly during the first monsoon after it had been built upon, and seem mainly due to direct wave action, at low water, but partly also to compression of the rubble, and to its sinking into the sand. The flood-tide has scoured out much sand at the head of the breakwater, acting most at about 200 feet south-east of the end, where a hole 14 feet deep has been formed, down to the clay, at 42 feet below low water. The rubble apron seems, however, sufficient to guard against this action affecting the breakwater.

10. Results.

The shelter afforded by the breakwater has so far proved effectual in stilling the entrance channel, as to keep it free from deposit except at the inner end, where some shoaling still takes place, through causes beyond the influence of the breakwater, which are either capable of removal, or are likely to be remedied by time. The outer limit of this shelter varies somewhat with high and low water; when the waves are at the highest, say 15 feet, outside the breakwater, the wave at the outer end of the entrance channel is generally about 5 feet in height, and gradually lowers to smooth water at the inner end. The lower outside waves are reduced in about similar proportion.

The breakwater has of course deflected the flood-tide to a greater circuit; but, though it must be looked on as some disadvantage that the main streams of flood and ebb do not take the same line in

the entrance, yet no injury has been done to the flood in its principal function of filling the harbour and backwater.

As regards deposits on either side of the breakwater, no diminution of the original depth has taken place, excepting to the limited extent to be expected in the shore angles, especially on the harbour side. During the progress of the work, however, there had been some scouring away of the sandy bottom through the action of the flood-tide along the harbour side; but since the completion of the breakwater accumulation has taken place to the extent of restoring the bottom to its original level.

11. Cost.

The total cost of the breakwater, the details of which are given in the Appendix, was £93,565, or £62 5*s.* per lineal foot; but the work was being advanced at the rate of £34 per lineal foot for current expenses at the time of its completion. This is exclusive of the cost of engineering and office establishments, which was borne on a general account for the whole of the harbour works, and amounted to nearly 16 per cent. on their net total, the percentage having been increased by suspensions and delays. The cost will, it is considered, compare favourably with that of similar works in Europe, when it is borne in mind that materials were 25 per cent. to 100 per cent. dearer (the latter rate especially applying to the important items of cement and timber), that plant had to be imported from England, and that European agency and workmanship cost about double English rates. Even the local labour cost as much as similar work in England; for though the wages of the native workpeople were low as compared with English rates (though high for India), their outturn of work generally bore about the same ratio. Suspension, and short supply of funds, also enhanced the cost in the earlier stages of the work. The statement of the cost includes the repairs, not only during the progress of the work, but also, as a fair charge against first cost, for the two monsoons which have elapsed since its completion. The cost of the breakwater, including percentage for engineering and office establishments, was nearly £109,000, or £1,000 less than Mr. Walker's original estimate.

12. Agency.

The breakwater works were carried out in the Bombay Public Works Department, by the Author and his assistants, advised by Mr. William Parkes, M. Inst. C.E., as Consulting Engineer. The

works were not as a whole let on contract; but contracts were resorted to for all portions except the erection, working, and repairs of engines and machinery, and the construction and maintenance of railway lines.

After the promotion of Captain (now Major) Merewether, R.E., in October 1870, to the charge of the Bombay Defence Works, the staff on the breakwater works consisted of Mr. George William Lowe, foreman of masonwork; Mr. William Sangster, foreman engineer; Mr. Bhumaya Saenna, supervisor, and Mr. John Humby, sub-engineer. The completion of the work was favourably noticed by the Secretary of State for India, the Governments of India and of Bombay, and the Commissioner in Sind. The Author proceeded on furlough to Europe in April 1874, and Mr. J. H. E. Hart, M. Inst. C.E., now holds charge.

13. Concluding Remarks.

In conclusion, it is submitted that the results, as to time of execution, stability, and cost, have been such as to warrant the construction and the means adopted. The absence of bond, and the inclination of the blocks, while facilitating execution and repair, enabled the structure to accommodate itself to the action of the sea and of settlement without fracture or serious dislocation; and the Titan proved an efficient and speedy means of setting, without the expense and difficulty of staging. Excepting the outer end, which ought undoubtedly to have been secured in a special manner, no damage whatever has occurred during the two monsoons to the outer half-length, which was founded on a regular base in deep water. The damage to the shoreward half on the irregular bottom might probably have been obviated by the employment of much larger masses so as to dispense with a centre joint; but only at an extra outlay which would have been far beyond the advantage gained.

No serious displacement has occurred below the top course, and even in that no gap has been made in the sea-side row; so that the cost of repairs has not been heavy, and will probably be lighter when settlement shall have ceased, though even if the superstructure were to lose its present regular form, it would still be efficient for shelter.

The communication is accompanied by a series of diagrams, from which Plates 1 to 4 have been compiled.

[Appendix.

APPENDIX.

DETAILS OF COST.

Materials and Works.	Quantities.	Amount.	
	Tons.	£.	
Rubble base	96,693	17,196	
Foreshore rubble in angles	5,059	841	
Shore end and 'stable'	—	1,963	
	Sup. yds.		
Diving work, Note A	3,903	2,491	
	Cub. yds.		
Concrete block-making, Note B	29,179	25,471	
Block-setting, Note C	28,970	6,303	
Repair of sea damage, Note D	—	1,314	
Total			£55,579
Plant and Auxiliary Items.		£.	
Preliminary, miscellaneous, and after expenses, Note E		4,179	
Plant, Note F		16,667	
Buildings, Note G		8,869	
Approaches, Note H		3,335	
Concrete-mixing station, Note I		1,103	
Block-ground		2,399	
Experiments on cement, lime, and concrete		231	
Share of surveys and observations		1,203	
Total			£37,986
Grand total			£93,565

NOTE.—The above does not include engineering and office expenses, which were borne in a general account for all the harbour improvement works.

NOTE A.—DIVING WORK.

The current working expenses during the three seasons were respectively 16*s*. 11*d*., 13*s*. 8*d*., and 8*s*. 6*d*. per superficial yard.

NOTE B.—CONCRETE BLOCK-MAKING.

After the work had been fairly established, the cost of each block of 16 cubic yards, for current expenses of materials and manufacture, also repair (but not first cost) of plant, was 122 rupees, or about 15*s*. per cubic yard. In the earlier stages of the work, however, the rate was considerably higher, owing to greater cost in working and materials, and to the larger proportion of cement used.

NOTE C.—BLOCK-SETTING.

The current working expenses during the three seasons were respectively 4*s*. 10*d*., 4*s*. 6½*d*., and 3*s*. 6*d*. per cubic yard.

Note D.—Repair of Damage by the Sea.

Of monsoon of 1871	£185
" 1872	512
" 1873	199
" 1874, of which about one-half was for refixing and alterations of the beacon on the outer end	418
Total	£1,314

Note E.—Preliminary, Miscellaneous, and after Expenses.

This item includes pay and travelling expenses of the foremen and divers from and to England, their pay and other losses during suspension under the "deficit" orders in 1869–70; also charges for medical attendance, hospital, water supply, conservancy, police, and other miscellaneous expenses beyond those of the actual working seasons.

Note F.—Plant.

Plant procured specially for the Breakwater, including freight from England.

	Cost.	
'Titan,' including erection	£2,879	
'Goliath,' "	1,010	
Rails, 54 lbs. per yard, 4 miles, with spikes, chairs, twenty sets of points and crossings, and four turntables . .	4,667	
Tank locomotive, including erection and spare gear . .	2,126	
Ten trucks for blocks	1,298	
Balk timber, squared sleepers, planks, and blockings, for breakwater roads	2,033	
Diving apparatus	378	
Sundry materials and stores for repairing old plant, and for general purposes	1,356	
Total first cost	£15,747	
Deduct, value after completion, one-fourth	3,937	
A. Net cost of special plant		£11,810

Plant transferred from other Works.

	Original Cost.
Workshop engine, 20-HP., and machinery	£2,458
Five hand-travellers, including erection and alterations .	1,627
Tip-wagons for stone and earth, platform, break and water-trucks, also trollies	9,550
Portable cranes, two 8-ton, two 4-ton	815
Derrick cranes, two 10-ton	498
Crane and sling chains, blocks and gin wheels . . .	594
Railway sleepers	1,715
Diving apparatus	172
Weighbridge and turntable	148
Carried forward	£17,572

		Original cost.	
Brought forward		£17,572	
Piling engines and hand-pumps		229	
Quarry, smith's, and platelayer's tools		841	
Miscellaneous plant and tools		785	
Total, first cost		£19,427	
Deduct, value after completion, one-fourth. .	£4,856		
And two-thirds of the loss, which is chargeable to the previous works	9,714		
		£14,570	
B. Net cost of transferred plant			£4,857
Total of A and B			£16,667

NOTE G.—BUILDINGS.

Office, workshops, and store buildings, landing pier, quarters for staff and workmen . .	£9,711	
Repairs to the foregoing	558	
	£10,269	
Deduct, value of buildings, &c., as above, or of their materials, after completion	1,400	
Net charge for buildings . . . . . . ,		£8,869

NOTE H.—APPROACHES.

This item comprises the cost of the formation of through lines of approach and communication, 8,070 lineal feet, including a stone embankment along the sea-face of the block-ground, but not the cost of railway material, which is charged to Plant.

NOTE I.—CONCRETE-MIXING STATION.

Cost of four mixers, 8-HP. engine and boiler delivered at Manora		£683	
Cost of masonry, platform, roof, well, and setting up and fixing boiler, engine and machinery		688	
		£1,371	
Deduct, value of engine and machinery after completion, one-fourth first cost	£170		
Deduct, value of materials of roof, building, and platform	98		
		£268	
Net charge for concrete-mixing station			£1,103

[MR. PARKES

Mr. PARKES said he was sorry that the Author could not be present, but he should be glad to take advantage of any suggestions that might be offered, and as he was as responsible for the work as Mr. Price himself, he could give any explanations regarding it. The Author had been wise in confining the Paper to one feature in the scheme of harbour improvement at Kurrachee. The other parts of the scheme were of great interest, but were, at present, hardly adapted for the subject of a communication to the Institution. The results of the works of construction, though the works themselves were practically complete, were not yet fully developed. As explained, considerable improvements had been effected in the harbour. Reference had been made to the delay in the construction of the breakwater. In justice to Mr. James Walker, it should be known that this was not in accordance with his desire. Government overruled his advice in the matter, and only those works which increased the scour of the harbour had been carried out in the first instance; but their success was imperfect; and when the Government asked his advice after Mr. Walker's death, it was given most unhesitatingly in favour of the immediate construction of the breakwater. There was no great travel of sand coastwise; but whatever sand there was within reach of the waves was lifted by them and deposited as a steep ridge. When the scour caused by the formation of the groyne acted upon the bar, it made an attempt to drive a channel through, as long as fair weather lasted; but as soon as the monsoon came, the partially-formed channel was filled up by a narrow steep ridge. This went on for some time, and a great quantity of sand was washed out of the harbour and deposited in such a way as to lengthen the bar, so that the navigation was much worse than in the original state of the harbour. The breakwater was commenced in 1870; it was completed in 1875, and the result was quite in accordance with anticipation. As soon as shelter was given, the tendency to the formation of a ridge across the channel was stopped; the depth was rather greater after the monsoon than before, on account of the stirring up of the sand which helped the ebb tide to carry it out. Since the breakwater had been completed there had not been the slightest diminution of depth at the entrance. The entrance channel had been changed from a very circuitous one, with a depth of 14 feet at low water, and difficult of navigation, to a perfectly straight one, with a depth of 20 feet at low water, admitting the largest class of ships; and, as a rule, sailing ships could go in and out without the aid of steam. It was seldom that works of such character and extent had been carried out with

so little modification of the original plan. A better description of them and their results could scarcely be found than in Mr. Walker's original report. The only modification from his plan was in regard to the delay in the construction of the breakwater, necessitating a recourse to dredging. If the breakwater had been previously in existence the increased scour would probably have formed a permanent channel, without the necessity of dredging.

The breakwater might be said to have no foundation. The outer half rested on quicksand, and the inner half on quicksand diversified by unyielding masses of rock. He had doubted the possibility of making a regular building upon it, and had looked forward to the first half of the breakwater being ultimately a random pile of blocks like those at Port Said and Alexandria. With the exception of the accidental removal of a few blocks from the outer end, in consequence of stormy weather before the necessary security had been completed, the outer half had received no damage. It had sunk bodily into the sand to the extent of about 3 feet at the maximum; but that was all the change. There was no bond between the two walls, and an opinion was at one time entertained that that might be a source of weakness. It had not proved so, because where the settlement was regular, as in the outer half, the two walls had not separated; on the contrary, they jammed so close together, that in some cases the upper edges of the blocks in the centre joint had been chipped. There was a little tendency towards canting over to seaward, as the sea side settled a little more than the harbour side. By far the greatest amount of settlement was in the first season. The process might go on for a few years longer, but he did not think it would be a serious matter. The very low level of the breakwater was another point worthy of notice. It was now at about half-tide level. There was a depth of 4 feet over it at high water, but it was perfectly effectual as a breakwater. Indeed the Author thought the wave falling over it rather tended to neutralise the undulation on the harbour side. The diagram of the waves (Plate 2) should not be looked at too critically. Their height had been accurately measured, but their thickness was of course very much a matter of guesswork.

Mr. Brooks said when the subject of the Kurrachee harbour was brought under the notice of the Institution in 1863, during the reading of a Paper on the Sind Railway,[1] he condemned the proposed plan for the works, and spoke in favour of a recommendation

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii., pp. 451–479.

by Mr. Taylor, one of the hydrographers of the Indian Navy, that a pier should be made from the opposite shore to the eastward, and after passing over the Oyster Rocks should terminate rather beyond the head of Manora Point.[1] He also expressed the opinion that the construction of any breakwater at Manora Point would make the harbour of Kurrachee much more dangerous than it was before, and that opinion had been verified. The length of the dangerous sand had been nearly doubled since 1858, so that with a west or south-westerly wind a sailing vessel would have had the greatest possible difficulty in entering the harbour. He believed, the formation of the present useful channel was due to the dredging, and he should be glad to know how much money had been spent in that operation. Too much money could not be laid out in securing so noble an entrance to a harbour of such national importance.

Mr. JOHN FLEMING remarked that the defect of the earlier works was, that while during the fair season a certain improvement was observed at the entrance of the harbour, during the monsoon it was filled up again; but since the completion of the breakwater the channel had remained permanently open. During the last monsoon, a large steamer drawing 23 feet 8 inches passed out of the harbour with perfect ease, whereas in 1858 the official sailing directions declared it unsafe for vessels drawing over 15 feet at neap tides, and 17 feet at spring tides, even in fair weather, to attempt to enter or leave the harbour. This fact proved the works to be a great success.

Mr. REDMAN said there was one point of great practical interest as to which the Author might be able to give further information, viz., the displacement of the large masses of concrete. In a recent discussion upon the Papers on the Pier at Kustendjie and the Aberdeen Breakwater, the question was asked why the one should be so thick and the other so thin.[2] Sir John Hawkshaw then called attention to the dissimilarity of the two places—one in a tideless inland sea, and the other on a storm-beaten coast with a great rise of tide and an enormous offing. He also referred to the now celebrated concrete block at Wick, 45 feet in length, and 1,400 tons in weight, which went wandering about owing to the enormous power of the sea. Considering the fate of that block, and looking at the dimensions of the blocks displaced in the Kurrachee breakwater, the little journeyings of the latter should not occasion any

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii., pp. 487, 488.
[2] *Ibid.*, vol. xxxix., p. 148.

surprise. The scantling of the block at Wick was not stated, but taking it at 24 feet each way, it would represent a resistance of 1½ ton per superficial foot. In the series of dynamometer experiments by Mr. Thomas Stevenson on the opposite Scottish coast, with an offing as great, a sea as deep, and waves as high, a maximum result was shown of nearly 3 tons per superficial foot.[1] Having regard to the depth of the sea, and the character of the wave as described by Mr. Price, there would possibly be an impact of 1 ton to the superficial foot; now looking at it in the most favourable way, the edge of each block, 8 feet by 4 feet 6 inches, only offered a statical resistance of 15 cwt. Mr. Stoney, in a recent Paper[2] of great interest, had given an account of concrete blocks, weighing 300 tons, which he had successfully laid at a great depth below low water for a sea-wall in the Liffey; and the success of that work had induced him to advocate, with great force and plausibility, the application of such a system to marine works. Without going into the question of the enormous increase in machinery, no doubt the same talent that devised the Titan, and manipulated the 27-ton blocks, would equally grapple with them if six times as large. This would do away with the confessedly weak point of the work, the open joint in the centre, which caused the resilience of the two halves of the breakwater. The thickness being increased 50 per cent., each block would be about 240 tons; and the 4 feet 6 inches being increased to about 7 feet, the block would require 1½ ton per superficial foot to move it, as compared with 15 cwt. Looking at the result of the movement of the block at Wick, where the offing, the depth of water, and the height of the wave were similar to Kurrachee, but where the rise of the tide was 10 feet, as compared with 7 feet 6 inches, it was clear that if the blocks in the Kurrachee breakwater were six times as large, and the thickness increased 50 per cent., they would not be more than equivalent to the impact of the 15-feet wave described in the Paper. He did not offer these remarks in a hypercritical spirit, but considering the results obtained by Mr. Stoney, and those accomplished by the Author with smaller blocks, he threw out these suggestions as hints for any future extension.

Sir Henry Montgomery had watched the progress of the Kurrachee breakwater from its commencement, and, in the position which he filled in the Council of India, had done all that he

[1] *Vide* "Transactions of the Royal Society of Edinburgh," vol. xvi., part 1.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxvii., p. 332.

could to support Mr. Parkes, who had invariably expressed confidence in the principles on which he had acted, and had successfully overcome any little difficulties that had arisen. The breakwater was in full operation, and appeared likely to answer the purposes for which it was constructed. It was completed within the estimate—a rare occurrence either in India or in England. The free use of cement and of concrete as a substitute for cut stone had promoted the operations, happily brought to a close without a single fatal accident.

Sir Barrow Ellis remarked that he was not able to criticise the professional details of the work; but he could describe the state of Kurrachee harbour twenty-four years ago. When he first went there, it was with difficulty that the smaller class of steamers entered the port except at very high tides and in very calm weather. It was then necessary for passengers to land in a small boat; and the mole not having been completed, the boat was insufficient to bring them to the jetty. When landing in 1851, he had to exercise considerable agility in skipping from stone to stone in order to get upon firm ground. That state of things continued for some years, and he well remembered the great interest felt when a single sailing vessel, drawing, perhaps, 17 feet of water, entered the harbour and left it again in safety. These works had had, throughout, the benefit of the experience and the advice of Mr. Parkes, who was so much concerned in the original plan, and also the almost uninterrupted superintendence of Mr. Price; and to those circumstances the success of the work might be greatly attributed. He could not share in the opinion expressed by a previous speaker, that the good effect produced was solely the result of the dredging. That operation, however valuable, was merely subsidiary, and it ought not to have the credit due also to the other greater works, which had not only made the channel, but kept it open.

Lieutenant-General Tremenheere desired to bear testimony to the zeal, the energy and the ability with which Mr. Price had carried out his arduous labours. He regretted that they should have produced such a strain upon his physical powers as to prevent his attendance on that occasion. His exertions had been fully recognised by the authorities in India, and he had no doubt that they would be as fully appreciated by his professional brethren at home. During the time he was Chief Engineer in Sind, the harbour works at Kurrachee were carried out by Mr. Price under his general supervision; he was therefore fully cognisant of the value of his labours. The statement that, before the break-

water was completed, vessels of a greater depth than 13 feet could not enter the harbour, demanded notice and correction. In 1858, before anything had been done to the harbour, the least depth in the entrance-channel, as shown on the chart, was $16\frac{1}{4}$ feet. The rise of ordinary spring tides was stated by the Author to be $7\frac{1}{3}$ feet, which would give an available depth at high water of $23\frac{7}{12}$ feet. The highest spring tides rose 12 feet, which would give a total depth, at such times, of $28\frac{1}{4}$ feet. He would be glad to know the depth of the present dredged-channel, the total quantity of material removed, and the expense incurred. He had no wish to offer any observations on the construction of the breakwater; but it had occurred to him that there were a few points of detail upon which it might be desirable to learn the opinion of Mr. Parkes; for instance, whether the blocks, instead of being set on edge in three courses, might not have been laid flat, and whether some bond might not have been provided. These were matters which, no doubt, had been duly considered, and there were probably sufficient reasons for the course adopted. He did not offer these remarks in a spirit of criticism, but simply to elicit information. He offered his cordial congratulations to Mr. Parkes on the completion of the work, and on his good fortune in having had the co-operation, in carrying out his views, of so able an engineer as Mr. Price.

Mr. PARKES gave some explanations, but the substance of these observations would be found embodied in his reply through the Secretary.

Mr. HARRISON, President, said the Institution was greatly indebted to gentlemen like Sir Henry Montgomery, Sir Barrow Ellis, and General Tremenheere, who attended and took part in the discussions. With regard to the observations of Mr. Brooks, it should be remembered that a harbour was now formed, where there was none before, upon plans laid down many years ago by a former President of the Institution, Mr. Walker, and carried out under the able superintendence of Mr. Parkes. Whatever speculations might be made with regard to the adoption of another system, the fact was plain, that a successful operation had been accomplished. It was one of those cases which showed what the ingenuity of an Engineer could do in dealing with an entirely novel state of things. A practical lesson might be learned from it. There were frequent cases in which foundations had to be laid where there was no bottom. He had one such under his own superintendence, with which he hardly knew how to deal, the depth being 70 or 80 feet. He was proposing to deposit large masses of slag from ironworks, which could be obtained at a cheap rate, and when fully consolidated to

build on the slag a quay-wall of concrete. The building of a superstructure of loose blocks suggested that at a future time, when the settlement was complete, they might be taken up and replaced in a perfect form. Mr. Parkes was to be congratulated that he had accomplished his work within his estimate. However careful Engineers might be, such a result was exceptional.

Mr. WILFRID AIRY remarked, through the Secretary, that he thought one of the most interesting features of the Paper was the account of the action of the sea upon the breakwater. It appeared that the blocks which were displaced by the sea were on the harbour side of the breakwater, and that the blocks on the sea side of the breakwater, even when left unsupported in consequence of the displacement of the blocks on the harbour side, remained firm. He considered this circumstance pointed clearly to the manner in which the dislocation of the breakwater took place, and he imagined that it was as follows:—The central longitudinal joint of the breakwater, either from settlement of the foundation or from having been originally left unfilled, got filled with water by a sea, and before the water so lodged in the joint had time to leak away, it was struck violently by the broken water from the succeeding sea. This would cause an instantaneous and violent hydraulic pressure between the blocks, which might easily be sufficient to thrust them apart, and ultimately to push the harbour-side blocks (which would be least supported by the sea) quite off the breakwater. As soon as this had happened, the outer row of blocks would be relieved from the hydraulic shocks from within, and would be comparatively safe, as the pressure would always be in the same direction. He was fortified in this explanation after an inspection of the diagrams and photographs exhibited by the Author. The natural conclusion from these considerations was, that the upper joints of breakwaters should be carefully closed, and if by settlement cracks were formed or joints opened, they should be at once filled up to prevent the lodgment of water in them.

Mr. RUSSEL AITKEN observed, through the Secretary, that when he visited Kurrachee, in 1866, although the steamer drew but 15 feet, it bumped heavily on the bar, which then showed no signs of improvement. At the request of the late Commissioner in Sind, Mr. A. D. Robertson, he wrote a memorandum, which had been published in the Government papers. In this report it was stated that, as the sand forming the bar must come from the westward, "the only means to get rid of Kurrachee Bar is to stop the sand

going on to it" (from the westward, by constructing the Manora Breakwater) "and to dredge out the sand of which it is now composed." Up to this time, one of Mr. Walker's chief recommendations, viz., dredging on the bar, had been lost sight of, and scour only appeared to have been thought of. It was further pointed out in this Paper that, since Mr. Walker's report was written, the power of dredging-machines had so much increased, that in a work such as this it was better to trust to dredging than to scour, which was seldom or ever effectual in obtaining the depth of water necessary for navigation. He thought that the large expenditure incurred in diverting the waters passing through the Chinna Creek on to the bar might well have been dispensed with.

Captain E. K. Calver remarked, through the Secretary, that various documents connected with proposed works at Kurrachee Harbour had been forwarded to him in May 1866 for an opinion; this had reference to the projection of the works, and not to their construction. The circumstances of the locality were peculiar. The periodical monsoon and its heavy seas, the subjection of the tides to local disturbing causes, and the apparent uncertainty connected with the current movements, all suggested a certain amount of doubt while drawing conclusions concerning improvement works; so much so that, in the absence of a careful study of all the features of the locality upon the spot, with the view, if possible, of tracing them to their several causes, any opinion about remedial measures must be general, and perhaps not very reliable. Be that as it might, after mastering the details of the documents referred to, he came to the following conclusions:—A conditional approval of an extension of the Keamari groyne, and a disapproval of the Manora Breakwater. Respecting this latter work, it was interesting to note that, in a letter of the 15th of March, 1864, Mr. Parkes stated his belief that the ground which led the late Mr. Walker to project the Manora Breakwater was not tenable, viz., "the existence of a shore movement of sand round Manora Point; for subsequent observations show that there is little, if any, such movement." It was noticeable, however, that in the Paper mention had been made of a diminution of depth, to a limited extent, in the shore angles of the breakwater, which at least proved that there had been a coast-drift from west to east of a certain amount, which might, in time, make its existence obtrusively felt. The breakwater had also attached to it the drawback of deflecting the flood past the entrance, so that the flood and ebb streams did not act in the same line over the bar—one of the objects generally sought to be effected by works. It had been stated by the Author that the breakwater had

so far proved effectual in stilling the entrance-channel; but it was difficult to gather from this whether the nautical accessibility of the harbour had been improved thereby, enabling vessels to enter Kurrachee harbour with greater facility than had been the case before the breakwater was built. Considering as he did, that the breakwater was merely a prolongation of Manora Point—that it would neither interfere with, reduce, nor destroy, any agent to which the features about the promontory were owing—he could not resist the conclusion (nor did he now) that in time all the sandy accumulations which then existed about the Point would, in their general character, be reproduced at the end of the breakwater, with the additional drawback of their being further removed from the effect of the improved scour established by Keamari groyne. Time, of course, would alone show whether these views were correct. The first effects of the breakwater might be beneficial; but the permanent adjustment of the surrounding features to the new condition of things was the point to be regarded, and it was not till such equilibrium had been arrived at that the real value of the work itself could be determined. The special character of the case had already been mentioned; and the difficulty of forming an opinion about it deserving of confidence was further increased on account of the different views held as to the effective cause of the sandy features about Kurrachee Harbour. Colonel Tremenheere, the Chief Engineer at Sind at the time, held that a coast current from south-east to north-west (from the Indus) was an active agent of change in the locality, while Mr. Parkes, on the other hand, treated this as hypothetical; but it was upon correct information respecting such points as these that a reliable opinion must be dependent. Generally speaking, he held in 1866, as he held now after noting the contents of the Paper, that the adjustment of the length of Keamari groyne, a parallel work along the shore inside Manora Point, and vigorous dredging, were the measures most likely to meet the wants of the present and the future at the least cost. At the best, however, this was an opinion resulting from imperfect data, and was scarcely fitted to come into serious competition with that formed by Mr. Parkes, who had the advantage of an intimate acquaintance with the locality, and who had devoted to the case much careful study.

Sir John Coode remarked, through the Secretary, that the mode of setting the blocks with greatly-inclined beds was not novel, this system having been adopted by Telford in a portion of the north-east pier at Peterhead. It was also recommended by Colonel Askwith, R.E., who probably was unaware of Telford's work at

Peterhead, to the Committee for the construction of a harbour of refuge in Dover Bay in 1846. Nevertheless, Mr. Parkes, as the Engineer of the Manora Breakwater, was entitled to the credit of having been the first to use this method on a large scale; but it was not applicable in all cases, although the principle was suited for adoption at Kurrachee.

The form of the setting traveller was new, and had apparently been successful; it appeared, however, to be capable of improvement, by placing the crab at the rear end and running the chain through blocks mounted on a small 'monkey' travelling frame, and thus removing a considerable overhanging weight. He was not prepared to assent to the doctrine that the absence of bond was an advantage, but the contrary; it would have been preferable to have carried each block completely across the work from the sea face to the harbour face without any vertical joint, modifying the dimensions to meet this change. The work consisted, in fact, of two entirely independent walls, each 12 feet thick. Such a structure was not adapted to withstand the shock of heavy 'waves of translation,' such as were constantly encountered by sea-works in stormy latitudes. The walls might for a time resist the force of the 'waves of oscillation' ordinarily experienced at Kurrachee during the south-west monsoon; but the repeated removal of blocks, and the necessity for connecting those at the outer end by chain ties, seemed to indicate a want of strength in the work. These remarks were justified by the disturbances in the finished work, and did not refer to those which might have happened to unfinished portions in course of construction, when all sea-works were, of necessity, for a time, in a vulnerable condition. There seemed ground for apprehension that this breakwater in its finished state might hereafter suffer material damage from some gale of extraordinary force, such as would be found to occur once only in a long series of years.

The frank and explicit description in the Paper of the damage done by the sea from time to time, and the details of quantities and cost in the Appendix, were features especially worthy of commendation.

Mr. J. N. Douglass remarked, through the Secretary, that an account of the exact expense of such a work was especially interesting at the present time, when the more extended use of concrete blocks of large size was receiving considerable attention. The dimensions of the blocks adopted by Mr. Parkes appeared to be just sufficient to withstand the seas to which they had been exposed at Kurrachee; but there the seas were not nearly so

violent as on many parts of the coast of Great Britain. Heavier blocks having a larger margin on the side of safety would, in his opinion, have been preferable, where the exact force to which the work might be exposed could never be positively determined. The absence of bond, both longitudinally and laterally, deserved attention. With such a work set on a rubble bank, thrown in upon the natural bottom, he agreed that longitudinal bond was unnecessary, and would be, probably, mischievous; but lateral bond seemed to be especially advisable. The pier at Alderney was an instance of the want of such bond. Settlement of the sea side of the work had occurred there, and this being imperfectly bonded with, and supported by the inner portion, caused serious fractures and mischief. In the Manora Breakwater good lateral bond might have been obtained, at a small percentage of additional cost in providing more powerful machinery, by the adoption of blocks of the same thickness, but in one length for the whole width of the breakwater, and in two, instead of three tiers in height, one block being thus equal in weight to three of the present blocks, or about 81 tons each, and by moulding them with a groove and tongue at the joints. This groove and tongue, besides acting as a guide for each block in lowering it to its bed, would give additional lateral stability to such a work, and check the direct drift of the heavy seas through the joints.

Mr. Alfred Giles stated, through the Secretary, that he did not agree with Mr. Brooks in believing that the harbour mouth at Kurrachee could have been kept continuously open without the shelter of the breakwater at Manora Point. The travel of sand along the coast from the westward would, during heavy weather, naturally tend to fill up any artificial channel round the Point, and the dredging operations would consequently have to be renewed after every monsoon; the entrance to the harbour would therefore have been not only uncertain and precarious, but expensive to maintain. He would have preferred to have given the breakwater a little more slant to the south, thus making it nearly parallel with the entrance, and better able to withstand the heavy seas by receiving them at a more acute angle. Great credit was due to the Author for the rapidity and economy with which the works had been carried out. He approved of the method of setting the blocks at a slight angle; at the same time he considered the absence of bond in the centre disadvantageous, and he feared the damage to the work already occasioned by exceptional weather proved the section to be rather light for the heavy seas the breakwater would have to encounter.

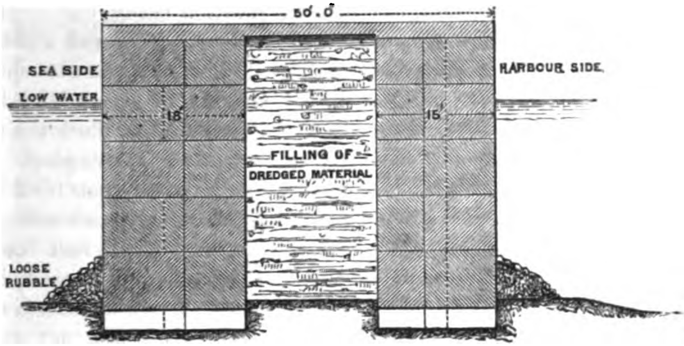
Captain E. Giles, I.N., who, from 1857 to 1873, had filled the office of Master Attendant at the Kurrachee Harbour, remarked, through the Secretary, that in 1857 the east (main entrance) channel took a circuitous bend round the tail of the bar or sand spit extending from Manora Point to the eastward. In this channel the average depth varied from 18 feet to 19 feet at high-water neaps, and from 21 feet to 23 feet at high-water spring tides. With these depths it was, as a rule, possible in the fine weather season (September to May) to cross the bar at high water, with vessels drawing from 17 feet to 21 feet, according to the tides and the actual state of the weather on the day of entry. From May to September a different state of things prevailed, from the south-west monsoon rolling up so heavy a swell as to make it a necessity that vessels crossing the bar should have a depth of at least from 6 feet to 7 feet of water under them. At this season then the extreme depth at which ships could enter or leave port was from 13 feet to 17 feet at neap, or spring tides respectively, and even at these depths they were fortunate to cross the bar without bumping. In addition to this east channel (as above) a slight depression ran across the bar spit, close under Manora Point, very nearly on the site now filled by the new channel. This west channel, with some 3 feet to 4 feet less water in it than the east channel, lay well to windward, and was used by vessels of light draught, which were enabled to run through it into port under sail, with a free wind and following sea; it was useless, however, to outward-bound ships, as the swell directly heading them caused heavy pitching and consequent dangerous bumping. From the above it would be easily understood that the port of Kurrachee, as it existed before the improvement works commenced, was not capable of maintaining a regular trade at all seasons of the year by vessels of large size; and further, the safety of those ships that did use the port was a constant and never-ceasing source of anxiety to the harbour authorities. The improvement works had changed all this, or rather the Manora Breakwater had done so. The first work of improvement undertaken was the Keamari groyne, completed in 1863. By the greatly-increased scour produced by this work, large quantities of sand were removed from the harbour to be deposited in both the entrance channels, adding for a time greatly to the difficulties of navigation. This temporary evil reached its climax in 1865–66, when matters, although getting worse in the east channel, began slowly to mend in the west channel. The improvement in the latter channel it was considered advisable to aid by dredging, and to a certain extent the result was satisfactory. It was, however, soon seen that, without

shelter from the south-west monsoon swell, the depth necessary for large vessels could not be maintained throughout the year, and the breakwater, which had effectually given this shelter, was commenced. In the meantime the tidal scour, being diverted, as it had been always hoped and intended, into the new channel, the eastern entrance continued to silt up, and in 1871 the buoys were removed, the use of this channel was abandoned, the whole traffic of the port being conducted through the new channel. In 1873 the breakwater was completed, and by its aid, togethor with scour and dredging, this channel, which had been year by year improving, since the commencement of the breakwater, was, for the first time, maintained through the south-west monsoon with a depth in it of 20 feet at low water. This depth had since been maintained, while the channel had been widened and improved by dredging to an extent sufficient to permit laden vessels of the largest class to enter or leave port at all seasons of the year. The new entrance to the port being then all that could be desired, it only rested with the authorities to so far improve the interior, either by docks, as proposed by the late Mr. Walker, or by dredging, as to enable Kurrachee to accommodate a trade of the largest kind.

Mr. HAYTER observed, through the Secretary, that Sir John Hawkshaw and Mr. Charles Hutton Gregory, Past-Presidents Inst. C.E., had been consulted in 1873 by the Molehead Commissioners of Bridgetown, Barbados, on the best means to improve the harbour of Bridgetown. Thereupon they recommended the construction of a pier or breakwater, with sloping or inclined courses of concrete blocks, the details of which he had worked out. The courses, however, instead of being without bond, as in the Manora Breakwater, had been bonded as far as practicable as shown in Figs. 1, 2, 3. There being no exceptionally heavy seas at Bridgetown, the smaller blocks were intended to weigh about 25 tons, and the larger blocks about 30 tons, and the bond was nowhere less than 3 feet. The courses were to be laid at an angle of 60°, instead of 75° or 76°, as in the Manora Breakwater. It was believed that by bonding the blocks, and laying them at a flatter angle, a more stable structure would be insured. The flatter angle would render it necessary to lengthen the jib of the 'Titan,' or overhanging crane used in setting the blocks, which would increase the size and cost of the machine, yet it was considered that this would be more than compensated for. Inclined courses might be useful when the foundation was bad, as the structure could better settle down without injurious displacement or cracking.

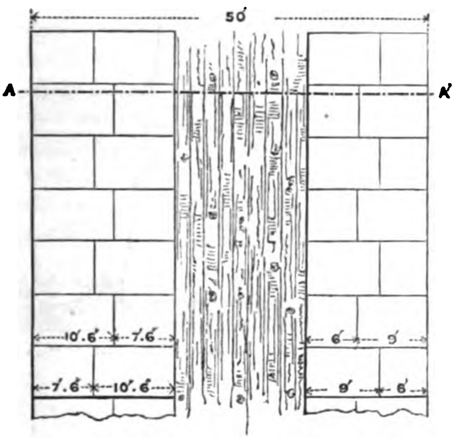
It might be well, however, to instance a case in which horizontal

FIG. 1.



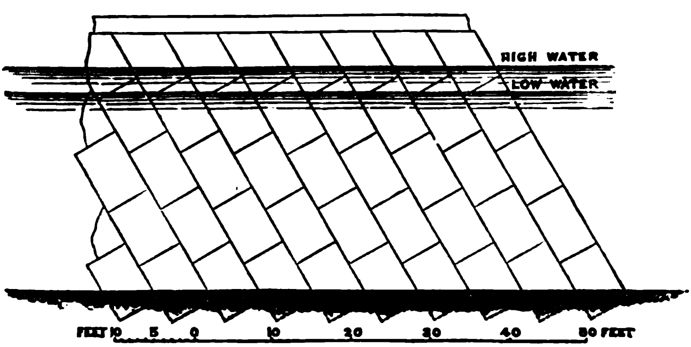
Cross section on line AA'.

FIG. 2.



Plan.

FIG. 3.

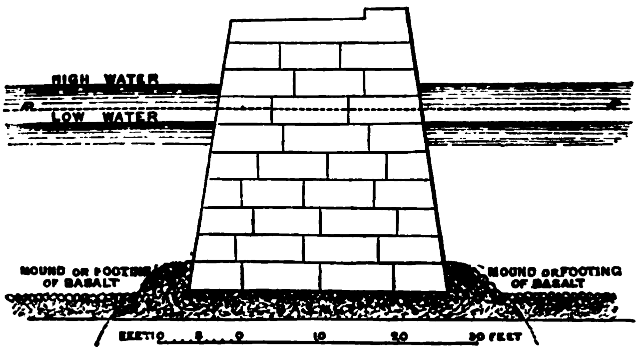


Elevation.

BREAKWATER AT BRIDGETOWN BARBADOS.

courses were adopted in piers built on a very unfavourable foundation consisting of quicksand, the case in question being the North Sea piers of the Amsterdam canal, which he had studied and which had been designed by Sir John Hawkshaw. (Fig. 4.) It was attempted at first to erect these piers by a timber staging of screw piles, but a slight disturbance of the sea excavated a hole round the piles, laying them bare, or sufficiently so to destroy the staging. This plan, therefore, had to be abandoned; and it was then tried to set the concrete blocks by a 'Titan,' after partially excavating the sand. It was hoped that when the bottom blocks had been set they would, notwithstanding the disturbance of the sand, find a bed which could be levelled, and upon which the structure could be raised. This mode of procedure, however, did not answer

FIG. 4.



AMSTERDAM CANAL—NORTH SEA PIERS.

satisfactorily; upon which Sir John Hawkshaw determined to substitute for the bottom course a layer of basalt thrown in 'pierre perdue.' The width of this mound was about three times that of the pier at the base, so that when the trench was excavated by the sea at the sides of the mound, the basalt fell into the hollow until it formed its normal slope, as shown by the dotted lines, leaving a central horizontal portion upon which to build the pier. This plan secured a good foundation, and it had been found that as the piers advanced (and they were now nearly completed) the trench, which in places had been no less than 26 feet deep, gradually filled up.

The system pursued at Kurrachee would probably fail where the seas were very heavy—as for instance at Alderney, or even at Holyhead—unless much heavier blocks were used, and

they were bonded. At the Manora Breakwater bonding might perhaps have been introduced with advantage. It was satisfactory that the work had been stated to be stable, and it might therefore be assumed that the expectations of the designer had been realised.

Mr. J. A. McConnochie stated, through the Secretary, that he had been engaged under the late Mr. Walker on the early designs for the Kurrachee Harbour improvements, and had been much interested in hearing periodically, during the progress of the works, of the success of the design for the Manora Breakwater; and he considered the information furnished by the Paper to be of unusual value to all engaged in sea works. The details of the Manora Breakwater had been designed by Mr. Parkes after the decease of Mr. Walker, and the novelties which Mr. Parkes had introduced in the designs had attracted the attention of all persons experienced in the construction of breakwater works, in exposed situations, on a rubble base. Whether the cost of this work, the rapidity with which it had been constructed, or the small amount of sea damage which had resulted, were regarded, they alike reflected the greatest credit on Mr. Parkes, and on Mr. Price who had executed the works; and proved that the principles of construction were correctly suited to the circumstances. Few, if any, sea works that he was acquainted with, unless it were at Alderney and Wick, were exposed as this to a lengthened hammering by waves measuring 15 feet from trough to crest. The two main features in this work which appeared to be the key to its success were the absence of horizontal bond, and the low level adopted for the top of the superstructure. The absence of horizontal bond admitted of the settlement, amounting to 3 feet, taking place without dislocation of the superstructure; the settlement, therefore, which had been the fruitful source of failure in works of this character with horizontally bonded masonry, was here harmless. The low level of the top of the breakwater, nearly 3 feet below high water, prevented the scooping away of the base and foreshore by the back-lash or recoil of the sea, an invariable feature with the high superstructures so often adopted in breakwaters, causing danger to the work, and heavy cost in maintenance. In this case the foreshore, of stones not exceeding 4 tons in weight, remained undisturbed at a depth of 15 feet at low water, and from his experience of high superstructure works, in anything approaching the monsoon exposure at Kurrachee, a foreshore with stones of this weight could not be maintained at so high a level. The observations recorded in the Paper showed that the shelter afforded by the

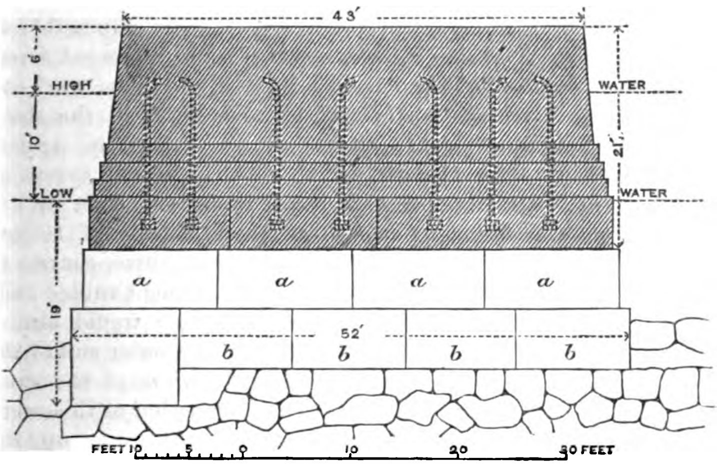
breakwater at this low level enabled an open boat to approach it within 100 feet at the height of the monsoon, and that it efficiently served the purpose for which it was designed. The middle line joint was doubtless a weak point, but this applied only to the top course, and principally on the harbour-side row of blocks, and the chain ties adopted at the outer end, which might with advantage be adopted throughout, effectually secured the work, while they admitted of unequal settlement between the sea and harbour rows of blocks. He believed this system of masonry, dispensing with horizontal bond, was the correct construction for a superstructure on a base of this character, and might be adopted with economy and advantage on other and more solid foundations under water.

The remarks of Lieutenant-General Tremenheere had reference more to the whole scheme of the Harbour improvements than to the immediate subject of the Paper, and indicated that he still considered the improvement in the entrance to be due to dredging alone. Without the shelter afforded by the Manora Breakwater the straight deep-water channel across the bar, which had so materially improved the entrance, would have been filled up to a great extent with the sand disturbed by the waves of the first monsoon after it had been dredged. Much of the cost of the dredging would have been saved if the breakwater had not been so long delayed. Judicious dredging, combined with the shelter of the breakwater, had here been attended with results as successful as those obtained, under somewhat similar circumstances, from the works at the mouth of the river Tyne. The Kurrachee works as a whole had, under the careful direction of Mr. Parkes, fully realised the expectations of the late Mr. Walker, and they afforded an instructive example of harbour engineering.

Mr. David Stevenson remarked, through the Secretary, that at the close of 1867, after five seasons' work, the superstructure of Wick breakwater had been built to a distance of 820 feet from high-water mark, and the rubble base had been deposited 250 feet farther, the total distance to the end of the staging being 1,050 feet; and that up to that period the works had suffered very little damage from storms, the amount expended in repairs being only a few hundred pounds. The superstructure of the breakwater was, in 1868, extended to 1,050 feet into the bay, the extreme length attained. Subsequently a succession of storms carried away a length of 223 feet from the extremity, and the breakwater was at present 827 feet long, terminating in a depth of 5 fathoms at low water of spring tides. The extraordinarily

heavy action of the sea was not fully developed until the work had been so far extended that the curved wave which entered the bay impinged on the breakwater nearly at right angles to its line of direction. This outer and exposed part of the breakwater was founded on a mass of rubble at the level of nowhere less than 18 feet below low water of spring tides. The breakwater was carried up to the level of 11 feet above high water, where it was 43 feet in breadth, and on the seaward side there was a parapet wall measuring 12 feet thick at the base and 9 feet at the coping, which was 21 feet above high-water level. This breakwater was very much stronger than that proposed for Wick Bay by the Harbours of

FIG. 5.



WICK BREAKWATER.

Elevation of the end, showing, by diagonal shading, the mass of 1,350 tons removed entire by the waves.
a a. Course of 80-ton cement blocks also removed by the sea.
b b. Course of foundation 100-ton cement blocks not moved by the sea.

Refuge Commission, in 1859. It had been founded at 18 feet below low water instead of 12 feet; it had been carried 11 feet instead of 6 feet above high water, and the areas of the sections of the two breakwaters were as 213 to 148 square yards, or as 1·43 to 1. In all its dimensions therefore the breakwater, as executed, was a far stronger work than that proposed by the Commission. The height of the waves by which the works had, on various occasions, been assailed, and which had carried away the outer portion of the work, had been estimated by the Resident Engineer at 42 feet from crest to hollow. They passed over the top of the parapet in masses of solid water estimated from 25 feet to 30 feet deep, and, as

ascertained by photographic views, the clouds of spray were projected to a height of not less than 150 feet. During one of these storms, two stones, of 8 tons and 10 tons weight respectively, had been carried over the parapet and lodged on the roadway of the breakwater. He was not aware of any harbour work which had been subjected to such powerful and destructive waves, of a magnitude, moreover, disproportioned to the normal depth of the water in Wick Bay. The experience gained at Wick had proved beyond question that these waves did not affect the foundations of the walls, which had been founded at the level of 18 feet below low water, all the damage having been confined to the superstructure, and extending about 10 feet under low water, below which level the work was unharmed. Had the superstructure, however, resisted the force of the waves it was impossible to predict what might have been the result of such prolonged severe action upon the rubble base, as the failure of the upper work certainly afforded immediate and considerable relief to the shock on the foundations. After unsuccessfully struggling against repeated assaults of such seas, which were especially severe on the outer extremity of the breakwater, it was resolved in 1871 to construct a termination, by depositing three courses of 100-ton blocks on the rubble base, as a foundation for three courses of large flat stones, surmounted by a monolith of cement rubble built *in situ*. It was hoped that the precautions used would form a protection against further damage to the exposed outer end of the breakwater, but in December 1872 nearly the whole of the outer protecting work was carried away. The destruction of this work was thus described in a Report by Messrs. Stevenson to the Directors of the British Fishery Society:—"The end of the work was protected by a mass of cement rubble work. It was composed of three courses of large blocks, of 80 to 100 tons, which were deposited as a foundation on the rubble. Above this foundation there were three courses of large stones carefully set in cement, and the whole was surmounted by a large monolith of cement rubble measuring about 26 feet by 45 feet by 11 feet in thickness, and, at 16 feet to the ton, weighing upwards of 800 tons. This block was built *in situ*. As a further precaution iron rods, 3½ inches in diameter, were fixed in the uppermost of the foundation courses of cement rubble. These rods were carried through the courses of stonework by holes cut in the stone, and were finally embedded in the monolithic mass which formed the upper portion of the pier. The arrangement described would be readily understood from Fig. 5. Incredible as it might seem, the huge monolithic mass

succumbed to the force of the waves, and Mr. McDonald, the Resident Engineer, actually saw it from the adjacent cliff being gradually slewed round by successive strokes, until it was finally removed and deposited inside of the pier. It was not for some days after that an examination could be made of this singular phenomenon, but the result only gave rise to increased amazement at the feat which the waves had achieved. It was found on examination, by diving, that the 800-ton monolith forming the upper portion of the pier, which the Resident Engineer had seen in the act of being washed away, had carried with it the whole of the lower courses which were attached to it by the iron bolts, and that this enormous mass, weighing not less than 1,350 tons, and presenting an area of about 496 square feet to the sea,[1] had been removed *en masse*, and was resting entire on the rubble at the side of the pier, having sustained no damage but a slight fracture at the edges. A further examination also disclosed the fact that the lower or foundation course of 80-ton blocks, *b b*, Fig. 5, which were laid on the rubble, retained their positions unmoved. The second course of cement blocks, *a a*, on which the 1,350 tons rested, had been swept off after being relieved of the superincumbent weight, and some of them were found entire near the end of the breakwater. The removal of this protection left the end of the work open, and the storm which continued to rage for some days after the destruction of the cement-rubble defence, carried away about 150 feet of the masonry, which had been built solid throughout the whole breadth of the breakwater and set in cement. The same remarkable feature of former damage was strikingly apparent in the last damage, the foundations even to the outer extremity of the work remaining uninjured."

On his first visit to the spot he found that the 1,350-ton mass had, after being moved from its bed, settled down on the rubble quite clear of the inner face of the breakwater. As soon as the weather permitted, the work of restoring the protection thus carried away was resumed, and completed in 1873. In making this restoration much the same style of construction, as formerly, had been adopted. Two courses of 87-ton blocks were built on shore and floated out, and deposited on carefully-levelled foundations in the débris that had been left unmoved by the sea. The blocks

[1] The lower courses to which the monolith had been bolted extended across the whole width of the breakwater, but did not extend so far as 26 feet lengthwise, which was the length of the monolith.

forming these two courses were connected together by iron rods, $3\frac{1}{2}$ inches in diameter, built into them and extending upwards so as to lay hold of the upper monolith of cement rubble which had been built *in situ*. The mass of masonry forming the present termination of the breakwater contained about 1,500 yards of cement rubble, the weight of which was about 2,600 tons. Whether or not the billows known locally as the wild "rollers" of Wick Bay would leave this mass of masonry undisturbed remained to be seen. Mr. Stevenson could not avoid directing notice to the action of the British Fishery Society under circumstances of great difficulty and discouragement; the directors having never shrunk from endeavouring to carry out the object they had in view so long as funds remained at their disposal. Messrs. Stevenson's recommendation to deposit large concrete blocks in front of the outer part of the breakwater, as an additional protection, which had been approved of by Sir John Hawkshaw, Past-President Inst. C.E., and Mr. Rendel, had not, in consequence of want of funds, been as yet accomplished.

Mr. B. B. Stoney observed, through the Secretary, that the Manora Breakwater belonged to the class with vertical sides, but that it differed from the ordinary section in the top being near the level of high water, in place of extending many feet above it. This greatly reduced the cost; and as a wave screen, in that particular locality and with the ordinary direction of the monsoons, the Manora Breakwater appeared to have been fairly successful, for the Author stated that, in the height of the south-west monsoon, open boats approached within 100 feet of the inside of the breakwater. It should not, however, be forgotten that one of the collateral objects of an ordinary breakwater was to act as a wind, as well as a wave screen, and in most situations, with storms coming in various directions, a breakwater reaching only as far as high water would not answer that purpose.

In consequence of its peculiar mode of construction, and the waves breaking over it in every storm, the destruction of the Manora Breakwater could not be regarded as a very remote contingency—unless, indeed, the heavy plant used in its construction were kept constantly on the spot, and repairs were effected each fine season; for, from the Author's description, it appeared that a large number of blocks were annually displaced, besides settlements, movements and disturbances taking place of a peculiar and critical nature. Neither did the cost of the plant and the temporary works appear to bear out the Author's statement, that the stability and cost of the work had been such as to

warrant the construction and the means adopted. A large quantity of the plant was second-hand, and the work was debited with only one-fourth of its first cost; but in making comparisons with other systems of construction, it was fair to calculate the cost of the plant when new, as getting the use of second-hand plant was merely a matter of luck. The cost of plant and works, other than the permanent work, or the sum which was expended on preliminary expenses, experiments and surveys had been as follows:—

	£.
Special plant	15,747
Plant transferred	19,427
Office, stores, workshops, landing pier, &c.	10,269
Approaches	3,335
Concrete station	1,371
Block ground	2,399
	£52,548

In other words, £52,548 had been expended on plant and auxiliary works, to execute £55,579 worth of permanent works. When Mr. Stoney's Paper, on the construction of marine works with blocks of large size,[1] was read at the Institution in 1874, Mr. Parkes took exception to the cost of the special plant and auxiliary works used in Dublin for the 350-ton blocks, which amounted to £33,847, and claimed superior economy for the Kurrachee system; but it now appeared that the corresponding item for the latter work amounted to £52,548. Supposing the section of the superstructure adopted at Kurrachee to be the correct one, Mr. Stoney submitted that a permanent wall of the same section could be constructed, according to his system, with one hundred and fifty large blocks. Should any local settlement of the rubble base take place, it would only slightly affect a 350-ton block, 24 feet wide at the base, 24 feet high, and 10 feet long in the direction of the breakwater. Each individual block might settle slightly, but it would not split down the middle, or be washed into the harbour, or grind against its neighbours, or require costly plant to be maintained on the spot to pick it up and replace it in the breakwater.

Mr. Vernon-Harcourt observed, through the Secretary, that the method of construction adopted for the breakwater appeared very good; obviating the necessity of staging, which was so liable to damage from the sea, and often proved a cause of delay: though novel as a whole the position of the blocks resembled that adopted

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxvii., pp. 332–354.

at Kustendjie, and the 'Titan' was similar in principle to a 'Samson' which had been in use for many years at Alderney. The system seemed very suitable for jetties and breakwaters where a large expenditure on plant was undesirable; and the rate of execution was specially remarkable, exceeding the usual rate of progress of breakwaters, though a continuous spell of fine weather for four months in the year doubtless contributed to this result. The damage caused during the monsoons appeared to be due to unequal settlement, aided by a want of connection between the upper blocks of each set. Unequal settlement alone had not always led to damage, as the breakwater at St. Catherine's, Jersey, exemplified. The experience gained at Kurrachee tended to show that, in similar constructions, it would be desirable to connect the upper row of each set of blocks with each other, and with the course below; this might be done by bedding the top row of blocks in cement on the lower course, and also filling in the longitudinal joint between them with cement, leaving the joints across the breakwater open, so that each set of blocks would continue disconnected, but the two upper rows of each set would be united into one block. This would diminish the rapidity of execution, as the top blocks would have to be set near the time of low water; but in the present instance it might not have done so very materially, as the work was delayed by the excavation for the foundation course; and most breakwaters would have to be raised higher above the sea-level, so that the bottom of the top course would be ordinarily higher above low-water mark. It was to be hoped that the experience as to deposits at Kurrachee would not resemble that at Port Said, where a similar scour took place during the construction of the jetty, and a similar refilling afterwards, and where, subsequently, the deposit so much accumulated along the inner side that dredging had been resorted to for removing it.

Mr. Parkes, in reply, said the remarks on the Paper might be divided into two heads: First, comments on the results of the improvement works generally, and on the effect of the breakwater especially; and, secondly, on the construction of the breakwater itself as a work of art. Applying himself to the first of these heads, he would refer those who doubted the reality of the benefits accomplished to the clear and explicit statement of Captain Giles, the late Master-Attendant of the Port, who had been intimately acquainted with the harbour before the works were commenced, in its transition period while the works were in progress, and in its present state since the works were completed. With regard to the share which the breakwater had taken in pro-

ducing this result, General Tremenheere and Mr. Brooks appeared to deny it altogether; and their opinion was supported, in a qualified way, by Captain Calver, who in 1866 had recommended, in preference to it, dredging and an extension of the East Pier. In the determination of this point, almost everything depended on the question of the origin of the bar. As to this, some originally held that it was a deposit from the ebb-tide current, and the Layari river had been indicated as the source of the deposit. Others attributed it to the meeting of the ebb current with a supposed alongshore current from the westward; while a third party contended that it resulted from the meeting of the ebb-tide current with the monsoon swell. Detailed surveys and observations soon proved that the conditions necessary for the formation of a bar on these theories did not exist, while facts were obtained sufficient to bring the explanation within precise limits. During the south-west monsoon, Manora Point was surrounded by a heavy surf, formed by the breaking of the ocean waves on the shallow bottom near shore. Every broken wave tore up sand from the bottom, and carried it on shorewise until, rounding the east side of the Point, it spent itself in the sheltered area, and dropped the sand which it held in suspension. The sand thus deposited formed, in course of time, a shoal, on which in turn more waves broke, and it assumed under their action the characteristic form of a ridge with deep water on either side. Now this action, under which the bar was in a state of continuous, though possibly very slow growth, would not be prevented by an increase of scour or by dredging. All that one or the other could do would be to establish a counteracting operation. If, however, the belt of surf were divided by an extension of Manora Point, and the new extremity were planted at such a depth that the waves were no longer broken on the bottom (and thereby converted into waves of translation for the movement of sand), the conditions necessary for the growth of the bar, or its reproduction if once removed, would be annihilated. From this it would be seen that the object of the breakwater was to prevent the re-formation of the bar when it had been removed by other means. Now what were those other means? Contrary to the advice of Mr. Walker and Mr. Parkes, the Government, in the first instance, tried scour alone. But the scour brought with it an immense amount of deposit—new food for the bar so long as the conditions for the formation of a bar existed. While those conditions were in abeyance—during the fair season—the scour did its work; but the first monsoon re-established the conditions, and the ridge wa

re-formed, and higher than before. But the scour had not been idle; it found its outlet elsewhere, and its power for future action on the bar was gone. The old circuitous channel was reopened; and it was several years before the crest of the bar was again broken down. Had the breakwater been in existence when the scour caused by the Keamari Groyne was directed on the bar, the direct channel which began to form in the fair season of 1863 would have been maintained, and dredging would have been unnecessary; but the only chance for prompt action by scour was lost, and either dredging, or a very long period of time for the scour to do its work, became necessary. The former alternative was wisely chosen; 646,000 tons of sand were removed at a cost of £29,600, and the experience of three monsoons bore testimony to the permanency of the result. The total cost of the improvement works had been £450,000, of which about one-half had been especially devoted to the entrance, so that the proportion of £29,600 to the whole justified Sir Barrow Ellis's remark that dredging was only a subsidiary operation. Captain Calver had suggested the possibility that the beneficial effect of the breakwater was only temporary, and that the original state of things at the end of Manora Point would be ultimately reproduced at the end of the breakwater; but he thought that in putting forward this suggestion, sufficient weight had not been given to the essential difference between the end of a headland terminating in shallow water, and the end of a pier standing in comparatively deep water. In the former case the broken waves (of translation) were a continually disturbing force; in the latter case the unbroken waves (of oscillation) had little or no effect on the bottom.

He now passed to the question of construction. The system adopted had been undoubtedly an innovation, in the substitution of detached masses, depending for stability on their own weight irrespective of one another, for a continuous structure of masonry of which the rigidity was greater than the cohesive strength. It was gratifying to find that the correctness of this principle had been admitted, either expressly or by implication, by all who had taken part in the discussion. No one expressed a preference for the time-honoured system of horizontal beds and vertical joints well alternated in the successive courses. All went some way with the Author and Mr. Parkes, although not all agreeing in the expediency of the details that had been adopted. The suggestions related chiefly to the use of larger blocks, to bonding together the two walls, and to tying together the upper blocks of the two walls. With respect to the first suggestion, made in different

forms by Mr. Stoney, Mr. Redman, and Mr. Douglass, there could be no doubt that, from one point of view, the larger the blocks the better, the only limit being that they should not be too large for the cohesion of the material, and he would assume (though with a reservation if the argument should be carried into greater detail than was his present intention) that that limit had not been reached by the authors of any of the suggestions. That one point of view was stability. A block was stable in proportion to its height and in proportion to its dimensions transverse to the pier, but not in proportion to its dimensions parallel to the line of the pier. A remarkable illustration of this truth was shown in the fact that in the Manora Breakwater a solid mass of concrete, occupying the space of three blocks, and therefore of a weight of about 81 tons, had been displaced, while the 27-ton blocks adjacent to it on either side were unmoved. It was three times the weight of a single block, but, being at the same time three times the length, had three times the disturbing force brought to bear on it, while the elements of stability—height and breadth—were not increased. It was of importance, then, to bear in mind that weight simply was not a true measure of stability. The true measure was weight per lineal foot measured along the pier. From this one point of view, therefore, Mr. Parkes admitted that the larger the blocks the better; but there was another point of view, that of cost. Up to a certain point, the larger the blocks the cheaper would be the work; but there appeared to be a limit to this, and if that limit was beyond the minimum required for stability, further increase in the size of the blocks would be unjustifiable. He would assume, what appeared to be the general conclusion, and what certainly was his own, that the blocks at Kurrachee were practically stable; the question then was, would any advantage be gained by making them larger? Of all the alternative plans suggested, the only one based on an accomplished work was that of Mr. Stoney, who appeared to prefer the plan he himself had so successfully carried out at Dublin. That plan had already been laid before the Institution, and was most deservedly commended; but on the question of cost and rapidity of execution, it compared unfavourably with the plan adopted at Kurrachee. Mr. Stoney quoted some figures in opposition to this conclusion; but if the Dublin plant for lifting, conveying, and setting the blocks, had been substituted for the Kurrachee plant applicable to the same purposes, the charge against the Manora Breakwater would have been £66,548, instead of £52,548. Besides this, it was considered by the highest authorities that, however

admirable might be Mr. Stoney's plan for a sheltered situation, it was not practicable in an exposed position like that of the Manora Breakwater.

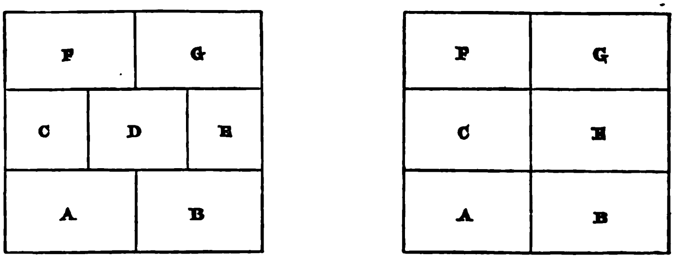
The suggestions of Mr. Redman and of Mr. Douglass had been made in general terms, and it would be unjust to compare such hypothetical schemes with the system adopted in a completed work. Mr. Redman would employ blocks of 240 tons, and Mr. Douglass blocks of 81 tons. As to the correctness of the principle Mr. Parkes concurred. The question was as to the practicability of their application, except at an expense disproportioned to the advantage. He was not prepared to deny the practicability of a system of land carriage for such blocks; but such a system would not be a mere extension of the Kurrachee system, it would be entirely novel. A setting machine might be devised capable of putting such blocks in place; but it would be no more like the Kurrachee 'Titan' than the latter was like its puny progenitor (as Mr. Vernon-Harcourt suggested it to be), the Alderney 'Samson.' Were the Kurrachee system modified so as to make it applicable to larger blocks, it would lead to questions of complication of machinery and strength of material which, in the absence of a definite plan, would seem to place such general suggestions beyond the pale of useful discussion. He had much pleasure in mentioning that his guiding precedents in the size of the blocks, and to a great extent in the handling of them, were furnished by the practice of Mr. P. J. Messent, M. Inst. C.E., at the Tyne piers, where blocks of 35 tons had been previously in use.

He now passed to the question of bonding the two walls together. In favour of this modification there was a strong concurrence of opinion of the highest authorities. General Tremenheere, Sir John Coode, Mr. Douglass, Mr. Giles, Mr. Hayter, and, through him, Sir John Hawkshaw and Mr. Gregory, were a formidable array; and Mr. Parkes freely admitted that if this discussion had taken place seven years ago, he would not have felt justified in opposing his own opinion, as he then held it, to such a weight of authority. He was now, however, thankful that he had not been exposed to such a trial. The opinion he then held had been strengthened by experience into a settled conviction, and he felt justified in maintaining it against the combined, but, he submitted, as yet untested, opinions of those high authorities. He laid claim, however, to no special prescience, for he had formed his original conclusion on reasons very different from, and less cogent than, those which had subsequently confirmed it. His original idea was simply of two walls, placed close together and back to back, without any hearting be-

tween them, because the 24 feet of double wall was wide enough for his purpose. Then the most solid form for each one of such walls seemed to be a pile of three blocks, of equal size. A middle course of three blocks to extend across the two walls was considered, but rejected on the grounds that it was impossible to bed a block (when uncemented) on two blocks so solidly as on one; that if a block of 27 tons were not too large for the work, then one of 18 tons would be too small, and a source of weakness; and that, inasmuch as it would cost as much to set a block of 18 tons as one of 27 tons, having to set seven blocks instead of six would add one-sixth to the total cost of setting. These reasons seemed to outweigh any real advantage to be gained from the 'bond course,' and they were quite independent of any question of the effect of bad foundation; indeed, he was prepared to find that no precautions could insure permanency of form in the first 500 feet from the shore, and he therefore abstained from giving any prominent expression to his hopes that the independence of the two walls would prove an element of stability over that difficult portion of the work. The result, however, gave to his previously somewhat vague and instinctive hopes a character of certainty, and he now pointed with confidence to the absence of bond as one of the most important features of the structure. The two diagrams (Fig. 6) might be taken to represent the bonded and unbonded sections respectively. Suppose them to be placed in such a situation that the foundation under block A yielded slightly, and that as the outside sank block C would follow it. Block D would ride on a ridge formed by the corner of block B. The outer side of block F would drop after C, and its inner side be lifted above the top of G. But the whole system D, F, and G would be balanced on the middle point of the lower bed of D, and form a kind of see-saw, hammering itself with every wave to ultimate destruction. Now trace the result of the same slight yielding of the foundation on the other section: A would drop as before, but C and F would follow it without any other disturbance of their positions than an opening of the centre joint, and a slight inclination outwards of the beds. This might take place to a considerable extent without endangering the stability of the structure. If it went too far, the block F would have to be removed, the top bed of C levelled down, and F reset at a somewhat lower level. If necessary, C might also be removed and reset; but as a matter of fact this had never been necessary. Under such circumstances as those described, and which were very ordinary ones at Kurrachee, Mr. Parkes could imagine no benefit, but much the contrary, from the insertion of block D. Another result of the presence of the

block D was worthy of consideration. It had been mentioned that the two walls were liable to a rocking motion, the centre joint opening and closing to a slight extent under the influence of the swell of the sea. This motion was perfectly harmless to the structure as it stood. It involved no friction and no hammering—no injury of any kind, unless it were to the limpets in the joints. But let the block D be inserted, and what would be the effect? The friction of the tails of F and G on the top of D might prevent this harmless swaying. But if it failed to do this, if F slid on D one way and G the other, was it quite certain that they would come back again? Might not the projecting corner of D prevent this, and F slide outwards on C in preference? Such a result might well be the beginning of a most destructive action. A modification of the foregoing remarks would be applicable to the section of the

FIG. 6.



Barbados breakwater, described by Mr. Hayter. The movements would be somewhat different from those of the blocks in the bonded section in Fig. 6, but the effect of unequal settlement would still be to separate surfaces whose contact was essential to the stability of the whole. It would not be difficult, by entering into a minute examination of the effects of the wave action on the structure, to adduce other ways in which the independence of the parts was an element of stability; but the above would suffice.

He would therefore pass on to the third suggestion, that of connecting the two top blocks. No one could be more alive than he had himself been to the importance of this. He had kept it in view from the first as a supplementary design, which should be based on the results of experience as to the best mode of accomplishing the object. But the result of experience had been this, that except in certain special cases, as at the exposed end, and also near the shore, where the top blocks on the harbour side had not been locked to the course below by stone joggles, no such con-

nection was needed. In these cases chains had been applied with good effect. Where irregular settlement had opened the centre joint, he considered it better to wait till a solid bearing was obtained before attempting to hold the blocks together, and it appeared that when this had been obtained there was no further occasion for the connection. It was a remarkable and rather unexpected result that where the bottom was uniform, however soft and yielding, the tendency was for the centre joint to close rather than to open. If it were decided at some future time, as was possible, to raise the structure to the height at which it was originally built, or perhaps rather higher, this would, no doubt, be done by forming concrete blocks *in sitû*, extending over the whole width of the breakwater; but it would be useless to do this until settlement had entirely ceased.

Having felt bound to meet many of the suggestions for improvements on the plan of this work by more or less qualified negatives, he thought it right to submit his own conclusions in a somewhat more affirmative form. As at present advised, he did not anticipate any advantage on the ground of stability, economy, or rapidity of execution, from the use of blocks exceeding 30 to 35 tons. If possible, he would prefer to dispose these in such a way that each should extend across the whole width of the work, and this might be done up to the limit of 16 or 18 feet; but where a greater width was required, he would prefer two, or even three, independent walls to any kind of transverse bond. The centre joint was a weak point only in so far as two 12-feet blocks were not so stable as one 24-feet block, but in no other sense; and the weak point was not to be strengthened by bonding, nor by prematurely connecting the two walls at the top, whether by chains or by a through capping block, while the foundation remained unsound.

Gloomy forebodings had been expressed of the ultimate destruction of the breakwater. So far, however, as reasons were given for these, they appeared to be based on misapprehension. The damage was not an annually recurring event. None at all had been sustained, except what was clearly attributable to imperfectly solidified foundations; and for two years no blocks had been removed but exceptional ones from the end. Possibly a weak place might even yet be here and there found out; but he could see no way in which the work could be liable to progressive deterioration. There was no necessity to keep the expensive plant on the ground for repairs. Wherever a block was lost it was best replaced by filling soft concrete into the vacancy, and this required nothing more expensive than a barge and a few planks. It was dangerous

to argue, from what an ordinary sea had done or failed to do, to what a much heavier sea might do; but with all proper reticence in this respect, he could not but think that a more minute examination of the actual effects of the sea would prove that there was still a considerable margin of stability in the Manora Breakwater.

All persons interested in sea work would feel deeply indebted to Mr. David Stevenson for his graphic and circumstantial description of the extraordinary phenomenon at Wick. Such a fact, so well authenticated, seemed almost to present the battle against the force of the waves as a hopeless one; but he would direct attention to the exceptional character of this case, and to the impossibility of ascertaining all the conditions which might have contributed to so extraordinary a result. Had this been simply the largest instance on record, standing at the head of a series of cases approaching to it by gradations, he would have been more disposed to draw general conclusions from the fact. But it seemed to stand alone. To argue from it would be to condemn as dangerous every sea barrier in existence, and to contradict the most trustworthy results of experience. In other respects Mr. Stevenson's testimony was encouraging. Mr. Parkes was glad to find him supporting the position that a high vertical sea wall with a parapet was an element of danger to the toe of the wall, and that even in such a tremendous sea as that at Wick blocks of a manageable size had been permanent at 10 feet below low water where the head of the wave could make a clean leap over the top of the work.

Representing as he did, in a certain sense, the Author of the Paper, eulogy of that gentleman would be out of place; but he could not conclude without for a moment dissociating himself from Mr. Price, for the purpose of bearing testimony to the ability with which he had conducted the works, and to the cordiality of his co-operation with himself.

November 16, 1875.

GEORGE ROBERT STEPHENSON, Vice-President, in the Chair.

No. 1,439.—"The Pneumatic Transmission of Telegrams."[1] By RICHARD SPELMAN CULLEY, M. Inst. C.E., and ROBERT SABINE, Assoc. Inst. C.E.

PART I.

THE transmission of telegrams by pneumatic power was first carried out between their Central Station and the Stock Exchange, in 1853, by the Electric and International Telegraph Company, through their Engineer, Mr. Latimer Clark, M. Inst. C.E. A tube was laid between those two places, and a vacuum was maintained by a small engine at the head office, so that whenever communication was made between the tube and the vacuum holder a current of air was established, from the Stock Exchange to the Central Station, which transported a gutta-percha carrier with it.

In 1858, the use of compressed air was introduced by Mr. Varley, M. Inst. C.E., for the outgoing traffic, retaining the vacuum principle for the incoming traffic. This was an important improvement, as it enabled messages to be forwarded both ways. The system was also introduced at an early date in Manchester, Liverpool, and Birmingham by the Electric and International Telegraph Company, and has been extended to Dublin and Glasgow by the Post Office. It will shortly be in action in Newcastle, and possibly before long in Edinburgh and Leith. In each instance the tubes radiate from a principal station (at which the engines are placed), and, as a rule, each tube serves but one branch station.

In the earlier arrangements, air vessels or reservoirs were employed to store up power; but as traffic increased, and the demand

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[1] The discussion upon this Paper was taken in conjunction with the succeeding one, and occupied portions of four evenings.

for a greater speed of transit had to be met, no interval of ti
left for accumulation. Under such circumstances reservoi
useless, except so far as they equalise the action of the pump
London, reservoirs have been entirely dispensed with.

During the earlier years of telegraphic enterprise, single li
pneumatic tubes amply sufficed both for the inward and f
outward traffic; but as business increased, the disadvantage of
lines[1] made itself felt, especially in London. Hence it was pro
to lay double lines to the more important stations, and to exte
system to the principal West End office at Charing Cross,
Fleet Street as an intermediate station, as it was not expected
the traffic would pay for separate lines to each of those sta
This would have been done, but for the agitation resulti
the purchase of the telegraphs by the State, the Electric Com
considering that no sufficient compensation would be obtaine
the purchase-money for the large outlay necessary for this
line of tube. But as soon as the purchase and the shilling t
had been decided on, so that a much larger traffic had to be
vided for, the Post Office determined both to double the exis
lines of tubes and to lay down a double line to Charing Cross.
doubling was carried out, in readiness for the removal of the cen
station from Telegraph Street to the new General Post Of
for it had become more than ever necessary, in consequenc
the increased distance of the new office from the centre of
business.

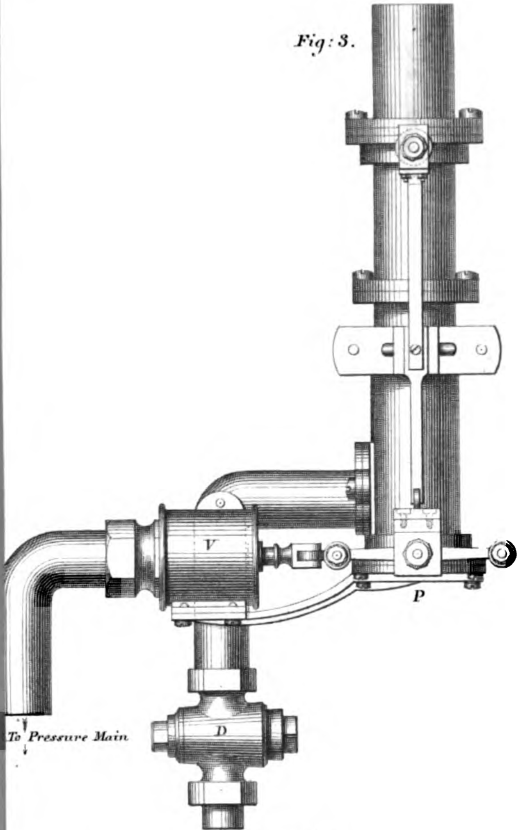
The Charing Cross tubes were at first worked on the 'circu
system, the up tube being connected to the down tube at
distant end, and the air made to circulate by being pumped i
one end and drawn out at the other. It was afterwards found th
nothing was gained by the circuit. The tubes were disconnect
at Charing Cross, and they have since been worked in the san
way as the rest of the Post Office pneumatic system.

The pneumatic tube system of England developed itself, from it
introduction in 1853, as the demands upon it increased. Whe
the traffic became too great for a single line, the line was doubled
when it became necessary for the carriers or boxes containing th
messages, to follow one another more rapidly, they were inserted i
the tube at as short intervals as practice showed to be safe.

The following is a list of the tubes in use at the commencement
of the present year.

[1] It is customary to think of a tube as if it were a line of railway.—R. S. C.
[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxiii., p. 29.

Fig: 3.



DOUBLE SLUICE PNEUMATIC VALVE. BACK VIEW.

Fig: 4.

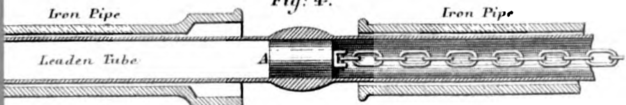
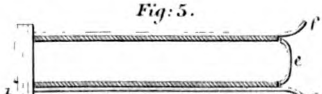


Fig: 5.



THOS KELL, LITH 40, KING ST COVENT GARD

POSTAL TELEGRAPHS, PNEUMATIC SYSTEM, 1ST JANUARY, 1875.

—	No. of Tubes.	Diameter.	Length.	Total length of Tubes.	
		Inches.	Yards.	Miles.	Yards.
LONDON	..	..	..	17	1,160
Central Station to Charing Cross, with Fleet Street intermediate	2	3	2,610		
Central Station to Lower Thames Street, with Cannon Street intermediate	2	2½	1,841		
Central Station to Stock Exchange	2	3	1,085		
" " Submarine Company's Office, Threadneedle Street	2	2½	1,095		
Central Station to Gresham House	2	..	1,289		
" " Leadenhall Street	2	..	1,290		
" " Fenchurch Street, Mincing Lane	2	..	1,409		
Central Station to General Post Office (Old)	2	..	157		
Central Station to Telegraph Street, Moorgate Street	1	..	917		
Central Station to Anglo-American Company's Office	1	..	1,057		
Central Station to Founder's Court Lothbury	1	..	808		
Central Station to Lloyd's	1	..	954		
" " Cornhill	1	..	965		
" " Baltic Coffee House	1	..	1,192		
" " Eastcheap	1	..	1,337		
" " Mark Lane	1	..	1,641		
" " Ludgate Circus	1	..	777		
LIVERPOOL	..	..	..	1	1,237
Central Station to Stock Exchange	2	2¼	791		
" " Water Street	1	1½	797		
" " Corn Exchange	1	..	618		
DUBLIN	..	..	..	1	940
Central Station to Four Courts	1	1½	1,300		
" " Custom House	1	..	700		
" " College Green	1	2¼	700		
MANCHESTER	..	..	..	1	266
Central Station to Thomas Street	1	1½	637		
" " New Exchange	1	2¼	451		
" " Stock Exchange	1	1½	413		
" " Mosley Street	1	..	300		
" " Post Office	1	..	225		
BIRMINGHAM	..	..	..	..	917
Central Station to Cannon Street	1	1½	240		
" " New Street Railway Station	1	..	140		
Cannon Street to Post Office	1	..	537		
GLASGOW	..	..	..	..	242
Central Station to Royal Exchange	1	2¼	242		

A description of the London system as at present constituted will suffice for all. The pneumatic tubes are worked from one centre, viz., the central station in the new General Post Office, at which point the engines and air-pumps are fixed. At that station the tubes are arranged vertically, side by side, and each is terminated by a valve. Those used exclusively for forwarding messages are situated at one end of a long table; those used both for forwarding and receiving in the centre, and those for receiving only at the other end. The messages for delivery by hand are sent through a tube to a room below, and there are several tubes for conveying messages to different parts of the gallery.

Sluices or Valves, and Method of Working (Plate 5).

The Varley valves,[1] though very efficient, are expensive in first cost, and troublesome to keep in order, because of their complexity. In providing for a system so large as that of the Post Office, it became necessary to devise a simpler arrangement.

The valves now employed admit of each tube being used either—

1. Exclusively for sending carriers to a distant station by means of compressed air; or
2. Exclusively for receiving carriers by means of vacuum; or
3. For sending or receiving at pleasure on the same tube.

Fig. 1 is a section, Fig. 2 a top view, and Fig. 3 a back view of the valve or sluice.

1. In sending, the carrier or piston-box containing the messages is inserted into the chamber M (Fig. 1) until it is held by the contraction at C, where the chamber narrows to the size of the tube. The handle H is next drawn forward, carrying with it the sluice S, which closes the mouth, P, of the chamber. The stop S′ now strikes the lower end of the lever O Q, pressing it into the slot *s* of the sliding bar B, and the continuation of the motion opens the upper slide T by means of the rack R. At the same time the inclined plane I (Fig. 2), attached to one of the sliding rods actuating the lower sluice S, passes between the fixed roller F and a roller fitted to the valve V, establishing communication between the pressure main and the message chamber, the compressed air expands the felt casing of the carrier, causes it to fit the tube, and forces the carrier forward. On its arrival being signalled electrically, the handle H (Fig. 1) is pushed inwards, the air cut off, and

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxiii., p. 21.

the message chamber opened ready for another carrier. The operations of opening and closing the slide occupy so short a time, and the resistance of the long pipe is so great, that if it be desired to send a second carrier before the first has reached its destination, the speed of the first is not sensibly affected. The cock D (Fig. 3) connected with the vacuum main is, of course, closed. By closing the top sluice before opening the lower one the rush of compressed air from the tube is prevented.

2. In receiving, the carrier is inserted at the distant end of the pipe, and is signalled. On receipt of the signal the lower sluice is closed, and the upper one is opened as before. Communication with the vacuum main is now established by opening the cock D (Fig. 3), and when the arrival of the carrier is known by its striking the lower sluice S (Fig. 1), or by observing it through a glazed opening in the message chamber, the vacuum is shut off by the cock D, and the handle H is pushed in. The top sluice being now closed, and the lower one opened, the carrier, having passed the contracted part C (Fig. 1), drops out. The connection between the valve V (Fig. 3) and the pressure main is cut off by a cock on the pipe E (Fig. 3), not shown in the drawing. Here again the operations of removing the carrier and of turning on the vacuum do not sensibly affect a following carrier.

3. In sending or receiving on the same tube, the upper sluice T (Fig. 1) is thrown out of use by removing the plug G, which connects it with the rack R and the quadrant O Q; it is opened and held back by a clamp. The manipulation is the same as before, except that in sending, after the carrier has arrived, the slide is at first pushed back only far enough to close the pressure valve V, so as to give the compressed air time to expand in the pipe before the lower sluice is opened. This prevents the noise of escaping air. In receiving, care must be taken not to move the handle so far as to open the pressure valve V.

Arrangements at Out-stations.

At the out-stations, the tubes terminate in a glass box, with a swinging door opening inwards. This door is closed by the pressure of the incoming air, and the air itself escapes through a pipe fitted at the bottom of the box; were it not for this provision the out-stations would be filled with air which had passed through the pumps. This pipe serves also as a drain to carry off the water used to clear obstructions in the tube. The message tube is fitted

into the top of the box, so that nothing can fall into it accidentally. Intermediate stations are fitted with the rocking sluice.[1]

MATERIAL FOR TUBES.

Lead has been used in every case except for the two tubes between Telegraph Street and Charing Cross, which are of iron. These iron tubes have been very troublesome, partly, no doubt, because the air-pumps of the engine constructed to work them were lubricated by a water injection, the vapour of which condensed and rusted the iron, but although the pumps in question have been out of use more than a year, oxidisation still goes on, and rust is brought out of the pipes in considerable quantities, while the wear and tear of carriers is excessive.[2] There is still moisture in both tubes, that worked by pressure being, of course, the damper of the two. The lead tubes are very slightly damp, and no inconvenience has ever arisen from that cause; but it is true less air passes through them, length for length, because of their smaller diameter. In Paris, although the tubes are of iron, they do not rust. The air is in most cases compressed by the direct pressure of cold water; and where pumps are used, they are carefully cooled by being immersed in cisterns filled with cold water. The air, therefore, contains little vapour of water, and condensation scarcely occurs. Besides this, the tubes are kept clean by the friction of the heavy 'pistons' which pass through them. The lead does not appear to wear at all, except in places where the pipe has been accidentally indented. A piece of the first lead tube laid, which has been in constant work for twenty-one years, shows no sign of wear, but is brilliantly polished by friction.

The employment of lead instead of iron for the recent large extension of the system was decided on by the experience previously gained. Lead had been shown to be practically indestructible, the joints of the pipe are easily made perfectly air-tight; it becomes polished by use, thereby reducing friction and the wear and tear of carriers. Iron, on the other hand, had been found to rust very quickly, and to destroy the carriers. It is true that the rust was greatly increased by the special cause already mentioned; but it would, under the best circumstances, be considerable, unless the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxiii., p. 6.

[2] It was stated during the discussion on Mr. Carl Siemens' Paper, *vide* Minutes of Proceedings Inst. C.E., vol. xxxiii., p. 25, that the cost of repairing the carriers used in the iron tubes was nearly fourfold that of those used in the lead tubes, although the carrier mileage in the latter was many times greater.

air as it issues from the pressure pumps were cooled below the temperature of the tube. But from this a loss of propelling power would arise; while damp, and therefore rust, would not be entirely prevented.

DIAMETER OF THE TUBES.

When the present extension was contemplated, the pneumatic pipes in use were of three different diameters, viz., 1½ inch, 2¼ inches, and 3 inches. The question as to the most economical diameter to employ in future resolved itself into drawing a balance between the advantage of increased speed obtained with the same effective pressure in a larger tube, and that of a less expenditure of engine power necessary for working a smaller tube. Or, when the same speed was obtained in two tubes of different diameters, with different pressures, then the question resolved itself into the relative expenditure of engine power. The capacity of the carriers must also enter into the consideration; but it was found that a 2¼-inch carrier would hold a sufficient number of messages to satisfy the traffic. It was proved conclusively by experiment that, with equal lengths, working with equal pressures, the times of transit of carriers through the three sizes of lead tubes were in the following proportion:—

Through a 3-inch tube . . .	100
„ 2¼ „ „ . . .	116
„ 1½ „ „ . . .	141

and that to effect the transits in those times the power required would be:

For the 3-inch tube . . .	100
„ 2¼ „ „ . . .	49
„ 1½ „ „ . . .	18

From these results, it appeared that, at the same effective pressures, a 2¼-inch tube would give a speed only 17 per cent. higher than a 1½-inch tube, with an expenditure of more than two and a half times the engine power; whilst a tube 3 inches in diameter would give a speed only 16 per cent. higher than a 2¼-inch tube, and would require more than double the engine power. It was therefore obvious that any increase in diameter beyond that actually necessary to fulfil the requirements of the service would be attended with waste of fuel. For the long lines contemplated it was, however, deemed inadvisable to use tubes of such small diameter as 1½ inch, and as the time saved by a 3-inch tube was

proved to be small in comparison with the extra engine power required to work it, it was decided to employ $2\frac{1}{4}$-inch tubes for all the new lines. The exact internal diameter of the whole of the lead tubes is $2\frac{3}{16}$ inches. The iron tubes to the West Strand and the Stock Exchange offices are of 3 inches internal diameter.

Laying the Lead Tubes (Plate 5).

The tubes are made in lengths of about 29 feet. Each length is laid in a wooden trough as soon as it is manufactured, so that it may be handled without fear of bending. A tightly-fitting polished steel 'mandril,' attached to a strong chain, is then drawn through it, to insure the pipe being smooth, cylindrical, and uniform throughout. It is necessary that the mandril should be lubricated with soft-soap, so that it may not injure the pipe. When laid, the leaden tubes are protected by being inclosed in ordinary cast-iron pipes.

The process of laying and jointing the tubes is as follows:—The leaden tubes, drawn and smoothed as already explained, are delivered from the wooden troughs to the trench prepared to receive them. The iron pipes are then drawn over the lead, leaving enough of the leaden pipe projecting to enable a 'plumber's joint' to be made; a strong chain is next passed through the length of tube to be joined on, and a polished mandril, A (Fig. 4), being heated and attached to this chain, is pushed half its length into the end of the pipe. The new length of tube is then forced over the projecting end of the mandril, so that the leaden tubes (the ends of which have been already cut flat by an apparatus made for the purpose) butt perfectly together, and a plumber's joint is made in the usual manner. The tube is thus air-tight, and the mandril keeps the surface of the tube under the joint as smooth as at any other part of its length. After the soldering process has been completed, the mandril is drawn out by the chain attached to it; the next length is drawn on, and the process repeated. Where it is necessary to deviate from a straight line, it is essential that the tubes be laid in a circular arc, whose radius shall not be less than 12 feet. The same care is necessary in entering the various stations, otherwise undue friction will arise, and curves would be introduced which might cause the carrier to stick fast.

Carriers.

The carriers or 'pistons' are similar to those employed by the Electric Telegraph Company, and consist of a cylindrical box of

gutta-percha (Fig. 5), covered with felt or drugget. The felt is allowed to project beyond the open end of the carrier in the rear as shown at *ff*, so that the pressure behind causes this portion to expand and to fit the pipe exactly. The front of the carrier is provided with a buffer or piston, *b*, formed of several pieces of felt, which just fits the leaden pipe. To prevent the messages getting out of the carrier, the end is closed by an elastic band, *e*, which can be stretched sufficiently to allow the messages to be put in. The weight of a service carrier is 2¾ ounces avoirdupois. Leather has been tried, and although, if properly prepared, it answers well for iron, it is unsuitable for lead. The object in this country has been to lessen the weight of the carrier as much as possible; but in Paris the mean weight of a train, consisting of a piston, called the locomotive, and five carriers of iron covered with leather, is 6·6 lbs.

Signalling.

Electric signals are used between the central station and the outlying stations, consisting of a single-stroke bell with indicator, to give notice of the departure and arrival of carriers, and to answer the necessary questions required in working.

Where there are intermediate stations the tube is worked on the block system, as if it were a railway. Experience shows that where great exactness in manipulation cannot be obtained it is necessary to allow only one train in each section of a tube, whether worked by vacuum or by pressure. But where there is no intermediate station, and where the tube can be carefully worked, carriers may be allowed to follow one another at short intervals in a tube worked by vacuum, although it is not perfectly safe to do so in one worked by pressure. In working by pressure it has been found that, notwithstanding a fair interval may be allowed, carriers are apt to overtake one another. For no two carriers travel in the same times, because of differences in fit, unless they are placed end to end.

If signalling be neglected, and a carrier happens to stick fast, being followed by several others, a block will ensue, which it will be difficult to clear, while the single carrier could readily have been dislodged. During the year 1874 no stoppages occurred in the lead tubes, and but two in the iron tubes, and these had been injured by workmen engaged in laying gas or water pipes. Provided due care be exercised in the construction of the work, interruptions of the service are of rare occurrence, except from neglected signalling.

Clearing Obstructions.

When carriers stick fast in the pipes, and cannot be moved either by compressing or by exhausting the air, the pipe is flooded with water, and the carriers forced past the obstruction by increased pressure. The water flows off by the drain-pipe at the distant station. All tubes are now fitted with a small pipe by which water may be admitted if necessary. As stoppages have been so infrequent, it has not been necessary to devise any very elaborate means of discovering the locality of a fault.[1] An approximate idea may be formed from the time the tube takes to discharge itself when filled with compressed air; and when the fault is not too distant from either end, the simple expedient of measuring by means of string attached to a carrier has been found sufficient. It has never been requisite to open a lead pipe to remove a carrier stopped by any other cause than imperfect construction or external injury, the position of which was known. The iron pipes have been more troublesome.

The engineer in charge of the Paris system has arranged a beautiful method of discovering the distance of a fault. The principle is that when a concussion is produced at the end of a tube filled with air, the wave is propagated in the air at the rate of 1,030 feet a second. When it encounters the obstacle it is reflected at the same rate. If then the time is noted which elapses between the departure and the return the distance can be calculated.[2]

The Engines.

The engines, which were built by Messrs. Eastons and Anderson, are of the Woolf type. The high-pressure cylinder is 17 inches in diameter, with 4 feet 1½ inch stroke, and the low-pressure cylinder is 25½ inches in diameter, with 5 feet 6 inches stroke. Wrought-iron double beams vibrating on wrought-iron gudgeons are supported by pedestals resting on entablatures, each carried by 6-inch columns on massive bed-plates. These in their turn are supported by heavy cast-iron frames resting on lower bed-plates secured to a layer of concrete 6 feet thick, which underlies the whole building. The foundation bolts are 6 feet long, with foot-lock plates on their lower ends, and are let down into holes about 15 inches in diameter, made in the bed of concrete, and then run up with Portland-cement

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[1] The position of faults caused by workmen is always known.—R. S. C.

[2] It is fully described in "Nature" of December 11, 1873.—R. S. C.

grout. Upon the lower bed-plate of each engine, and immediately under the beam, are two exhausting and compressing pumps, 35 inches in diameter, with 3 feet stroke, having pump-rods guided by parallel motions at both ends of the beams, those at the cylinder end guiding also the pairs of piston-rods. The pumps are arranged either to draw from an 18-inch vacuum main laid between the pumps, through hinged metal flap valves faced with leather, or to force through similar valves on the opposite side into two 15-inch pressure mains, which afterwards unite and form one 18-inch main. Each pump can be shut off from either main at pleasure by screw slide valves, and by similar valves air can be taken in from, or be discharged into, the atmosphere, instead of from and into the vacuum and pressure mains. The valves, four in each group, 3 inches by 4 inches, beat on gun-metal seats, which have been so arranged that they can be easily withdrawn and exchanged for reserve valves when out of order. Steam is supplied to the high-pressure cylinder at 70 lbs. pressure, and is distributed by double slides, arranged so that the expansion can be varied without stopping the engine, on altering the length of the cut-off slide by means of a right and left-handed screw. The condensers are under, but to one side of, the cylinders, and the trunk single-acting air-pumps, 18 inches in diameter, with 2 feet stroke, are under the outer ends of the crank shafts, and are worked by crank discs keyed on them, the connection to the condenser being by inclined 8-inch pipes. The injection water is taken from a tank under the battery room, supplied either from the deep well or from the water company's main in the building.

The air from and to the engines is conveyed by 18-inch round cast-iron pipes laid under the battery room into the boiler courtyard, where they merge into 18-inch by 9-inch flat pipes laid close to the walls; and, rising in the corners, ascend to the top floor, where they turn into the operating room and run side by side, a vacuum and a pressure main, under the battery of the transmitting instruments, to which they are connected by brass cocks and lead pipes.

There are several peculiarities in the engines. The first is the use of plunger air-pumps; another is the construction of the jet, which has been adopted from the condensers used in obtaining a vacuum in sugar machinery. Instead of a rose, each injection pipe is fitted with a couple of funnel mouths, or dispersers, so that the injection water is fully distributed and the jet just meets the incoming steam; and, although the condensers are not large, a high vacuum is obtained. A third peculiarity lies

in the method of working the slides. The two main slides are driven by a cross-head common to both, and lying close to the cylinders. The single rod descending from the centre of the cross-head is guided at the bottom, and driven through a rocking shaft by the eccentric. Wheel and sector gearing is used for shifting the valves at starting, should the engines get on or near a centre. The engines are fitted with governors of the Porter type; these governors do not operate on the expansion gear, but on throttle valves. Diagrams were taken of two engines; No. 1 was working with one of its pumps and compressing air to 10 lbs. above the atmosphere, the other exhausting to about 8·8 lbs. below, the expansion slide cutting off steam at $\frac{3}{8}$ of the stroke. This engine indicated 73·6 HP. at 25 revolutions, the compressing pump 35·5 HP., the vacuum pump 26·7 HP. Its efficiency was therefore 0·872. No. 2 was working both pumps, exhausting, and indicated an efficiency of 0·866, the engine being 61·45 HP., the pumps 53·25 HP.

Comparison of the English with the Continental Systems.

As a rule, on the Continent, each pneumatic line comprises several stations, this being the most economical arrangement as regards first cost. In some cases the tubes form a continuous circular line, in which the trains or carriers travel in one direction only; the stations becoming either the starting-points of fresh circles, or of direct single lines. In Paris the greater part of the stations are grouped in circles, but power is provided at every station so that each section makes a distinct line. By these means the transit is considerably accelerated, but at a great cost. The line between the Bourse and the central station is direct, and two—sometimes three—carriers are permitted to follow one another; but on the circular lines the trains only run every fifteen minutes, so that a comparatively small pumping power is required, there being time for accumulation.[1] The delay arising from this system would be fatal to the traffic of large towns in Great Britain, for it is obvious that if a message arrive but a second after a train has started, it may be twenty, or even twenty-five minutes in reaching its destination, even if lying in the same circle. Nor can many stations

[1] The Authors have received from M. Ch. Bontemps, the engineer in charge of the Paris pneumatic tubes, the following information:—

There are seventeen stations, and 14 miles of line. All the tubes are of iron of 2·719 inches internal diameter. There is no trace of oxidation, the air being cool when delivered into the tubes. There are two steam-engines, of 4 HP. and 6 HP. respectively, which serve about two-thirds of the system; the rest is

be included in the same circuit, but the communication between the central station and the more important branch or out-stations must be direct.

The public is perhaps exacting in its demands for speed, and never thinks of the cost. To conduct the message traffic with the despatch demanded, every cause of delay, however small, must be eliminated, whether it occur in the transfer from the receiving office to the instrument room, on the wire itself, in the delivery, or in the pneumatic tube. A delay of even ten minutes would be fatal to the Metropolitan traffic, so that where this limit is approached the tube must be replaced by the wire. Now when the same tube serves two out-stations, the time occupied by the carrier in running from the central to the nearer station is increased by the addition of the tube to the farther station. Other causes of delay are also introduced; for instance, that of sorting the messages, and of removing at the intermediate station those intended for that station.

In a circular system, including several stations worked with a continuous current of air, the tube is still further lengthened, and the speed reduced. There is also this inconvenience: if A, B, C, and D are four out-stations, connected by a circular tube starting from and terminating at the central office, and if the direction of the air-current is from A to D, then a message from the central office to D must pass through almost the entire tube, subject to the diminution of speed due to the lengthened tube, and to the delay caused by the arrangements for working the more complicated system. Where despatch is not of paramount importance, the circular system has advantages, by giving communication between each station on the route. In London, however, the traffic is almost entirely to and from the central station. To give an instance of the way in which speed and time of transit are

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served by direct water pressure. In the portion worked by the steam-engines the pressure at the moment of despatch is 23·6 inches of mercury, falling to 19·68 inches after a short time, and afterwards remaining constant, the engines continuing to pump throughout the transit of the train. Under these conditions the mean time of transit is—

For 6,693 feet	174 seconds
„ 4,593 „	90 „

The weight of the train of a piston and five carriers is 6·6 lbs.

The tube between the central station and the Bourse is 1 mile 1,521 yards, or 9,843 feet, in length. When a single carrier weighing 1·32 lb. is despatched with an initial vacuum of 18·9 inches, the time of transit is three minutes, and the final vacuum is 15·75 inches. The pistons and carriers are of iron covered with leather.

reduced by grouping stations:—The time between the central station and Cannon Street, an intermediate station on the Thames Street tube, is—(1) when the whole tube is in circuit, seventy-two seconds; (2) when it is divided at Cannon Street, fifty-six seconds. The distance between the central station and Cannon Street is 958 yards; and from the central station to Thames Street, 1,841 yards.

Cost of the Pneumatic as compared with the Electric System.

In the discussion on Mr. Carl Siemens' Paper an opinion was expressed that the adoption of the pneumatic system was a retrograde and costly expedient.[1] It would be obviously out of place to enter into details of departmental expenditure; but in order to show that the opinion referred to is not well founded, it may be stated that the annual expense of the tube system in London, including the pay of all engaged in working and maintaining it, and also interest at 3½ per cent. on the cost of tubes and engines, is barely two-thirds of the pay alone of the staff which would be required to telegraph the messages, neglecting altogether interest on the cost of wires and apparatus, their maintenance, and the cost of conveying the large amount of news for the press which now passes through the tubes.

PART II.

Theoretical Principles.

When it was decided to transfer the head telegraph station in London from Telegraph Street to the new General Post Office in St. Martin's-le-Grand, and an extension of the pneumatic system became necessary, it was determined to examine, more closely than had been done before, the theoretical principles which governed the flow of air through pipes, and the amount of engine power required to produce that flow, so as to obtain the maximum results of speed and accommodation with the minimum expenditure of power. The question was investigated by the Authors,[2] and tables were prepared, by means of which practical problems might be readily solved. The results of these inquiries are now placed, by permission of H.M. Postmaster General, at the service of The Institution of Civil Engineers.

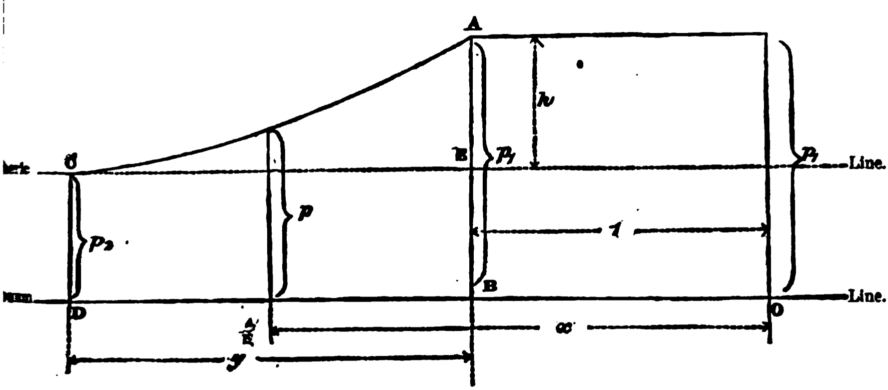
[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxiii., p. 50.
[2] *Vide* "Engineering," Sep. 23, 1870.

1. The Mechanical Effect performed by Air in expanding.

The transmission of a carrier from one end of a tube to the other is effected by the expansion of the denser air which enters the tube during the interval between the moment of starting and the moment of exit of the carrier.

In pressure-working, each transit costs exactly the force necessary to produce this volume of compressed air, whilst in vacuum-working each transit costs the force necessary to expand a corresponding volume of air at atmospheric pressure. This is obviously the case, because when the carrier arrives at the end of its journey, the tube has been filled behind it with just this volume of air at the higher pressure; and this volume is less than the whole volume of the tube by just so much as the air has expanded.

Fig. 1.



The absolute work (F) stored up in a unit volume of air at the effective pressure, h, is that exerted to compress it from p_2 to p_1, or that which it will return in expanding from p_1 to p_2, through the distance y, as has been already shown by Zeuner.

$$F = \int_{p_1}^{p_2} p\, dx\,;$$

$$\frac{p}{p_1} = \left(\frac{1}{x}\right)^n \therefore p = p_1 x^{-n} \therefore x = \left(\frac{p_1}{p}\right)^{\frac{1}{n}};$$

$$1)\quad F = \int_{p_1}^{p_2} p_1\, dx\, x^{-n} = \frac{p_1}{n-1}\left\{1 - \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}\right\}$$

in which $n = 1 \cdot 408$, the relation between the specific heat of dry

air, when maintained at a constant pressure and when maintained at a constant volume. For 1 cubic foot of air at p_1, the work (f) effected by it in expanding in the tube to p_2 is therefore

$$f = \frac{144\, p_1}{n-1}\left\{1 - \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}\right\} \quad . \quad . \quad . \quad \text{foot lbs.};$$

p_1 and p_2 being in lbs. per square inch, assuming that the air in expanding does not take up any heat through contact with the tube.

Inserting the numerical value of n, the work of 1 cubic foot becomes

$$2)\quad f = 352 \cdot 9\, p_1 \left\{1 - \left(\frac{p_2}{p_1}\right)^{0 \cdot 29}\right\} \quad . \quad . \quad . \quad \text{foot lbs.}$$

[log. 352·9 = 2·54770].

p_1 is always the greater pressure, and p_2 the lesser.

When pneumatic tubes are worked with compressed air, p_2 is atmospheric pressure (14·75); but when worked with vacuum, p_1 becomes the atmospheric pressure.

2. Volume of Denser Air which enters the Tube during the Transit.

Air passing through a tube expands as it goes on from the higher to the lower pressure, the expansion being nearly regular. Supposing that it neither gives to, nor takes from, the surface of the tube any heat, it would follow from the above that

$$\frac{s_1}{s_2} = \frac{v_1}{v_2} = \left(\frac{p_2}{p_1}\right)^{\frac{1}{n}};$$

s_1 being the velocity and v_1 the volume of the air as it enters, and s_2 the speed and v_2 the volume as it leaves the tube, p_1 the higher and p_2 the lower pressure.

Then if it be assumed that the pressure in the middle of the tube is a mean of the pressures at the ends, the velocity of entry of the denser air and the volume of it which enters between the starting and exit will be respectively[1]

$$3)\quad s_1 = s\left(\frac{p_1 + p_2}{2\, p_1}\right)^{\frac{1}{n}}$$

and

$$4)\quad v_1 = v\left(\frac{p_1 + p_2}{2\, p_1}\right)^{\frac{1}{n}}.$$

[1] In this consideration of the subject, the air after entering the tube is assumed to expand adiabatically. Its actual expansion is strictly neither adiabatic nor isothermal, but between the two. Calculated, however, on either assumption (provided only the assumption be maintained consistently through each operation), the result will be very nearly the same, and agree with the observations. The

3. Speed of Carriers and Air.

The effective work stored up in the denser air which enters the tube during the transit is expended in accelerating the speed of the carrier and the air, and in overcoming their frictions against the sides of the tube.

Accelerating the Air.—The work (A) expended in accelerating the air will be

$$5)\quad A = \frac{w\,v\,s_2^2}{2g}\quad . \quad . \quad . \quad . \quad \text{foot lbs.;}$$

s_2 being the velocity of greatest motion, and g the terrestrial acceleratrix $=32{\cdot}2$, both in feet per second, and w the mean weight of the whole of the air which moves in the tube during the transit, in lbs. per cubic foot.

Accelerating the Carrier.—If the weight of the carrier in the tube be W lbs., the work (B) of acceleration is

$$6)\quad B = W\,\frac{s_2^2}{2g}\quad . \quad . \quad . \quad . \quad \text{foot lbs.}$$

Friction of the Air.—After allowing for the work spent in acceleration of the air and of the carrier, the remaining work applied to propel them is, of course, consumed in overcoming their resistances to motion. The mechanical effect, C, absorbed by resistance to motion of air in passing through a tube of the length l feet, and diameter d feet, has been found to increase directly as the length and inversely as the diameter of the tube.

$$7)\quad C = \xi\frac{l}{d}.w\,v\,.\frac{s^2}{2g}\quad . \quad . \quad \text{foot lbs.;}$$

s being the mean velocity of the air in the tube.

The expenditure of power in overcoming the resistance of air to motion is more important than any of the rest, amounting in general to at least ten times all the others put together. There exists no definite and satisfactory determination of the value of the constant of friction ξ, which probably varies slightly, not only with the diameter, the material, and the condition of the surface of the tube, but likewise with the density of the air which is passing through. Experiments to determine its value have been made by Girard, D'Aubuisson, Buff, Pecqueur, and others, who give a mean value to it of $0{\cdot}02$. This value agrees with experiments with the lead tubes laid down in London, which are worked with felt

Authors have preferred to assume the expansion to be adiabatic, and have therefore taken into account the exact volumes of air which enter and leave the tubes upon this assumption. By this means the error which might be introduced by the expansion being affected by friction and conduction is practically eliminated.

carriers, and which have become to a great extent polished by continual passage to and fro. For the lengths of iron tubes, which appear, from the wear and tear of the felt carriers, to be exceedingly rough and wet, the value of this constant (ξ) appears to be about 0·028 or 0·03.

Friction of the Carriers.—Lastly, the work (D) consumed in friction of the carrier is

$$8)\quad D = \mu W l \quad . \quad . \quad . \quad \text{foot lbs.},$$

in which μ is the co-efficient of friction to motion between the material of the carrier and that of the tube. In some experiments with felt carriers it was found that the average weight was $2\frac{3}{4}$ oz., and that the friction to motion when in the tube was $1\frac{3}{4}$ oz.

The value $v_1 \times f$ foot lbs. of work is therefore balanced by the items of expenditure $(A + B + C + D)$, or $v_1 f = A + B + C + D$ (in which v_1 = volume of denser air which enters the tube during the transit).

Setting the algebraical values in this equation—

$$v f \left(\frac{p_1 + p_2}{2 p_1}\right)^{\frac{1}{n}} = \frac{w_2 v s_2^2}{2 g} + \frac{W s_2^2}{2 g} + \xi \frac{l}{d} \frac{w v s^2}{2 g} + \mu W l.$$

From which is obtained the mean velocity (s) with which the carrier travels—

$$9)\quad s = \sqrt{2 g \frac{v_1 f - \mu W l}{\left(\frac{p_1 + p_2}{2 p_2}\right)^{\frac{2}{n}} \left(W + w_2 v\right) + \xi \frac{l}{d} w v}} \quad . \quad . \quad \text{feet per sec.}$$

In practice, the friction of a dry carrier in a polished metal tube is so little, and the weight is so trifling, that both may be omitted without appreciable error.

The last equation then takes the form:

$$s = \sqrt{2 g \frac{f \left(\frac{p_1 + p_2}{2 p_1}\right)^{\frac{1}{n}}}{w_2 \left(\frac{p_1 + p_2}{2 p_2}\right)^{\frac{2}{n}} + \xi \frac{l}{d} w}} \quad . \quad . \quad . \quad \text{feet per sec.}$$

And when the tubes are very long in comparison with their diameters, that is to say, when the length exceeds 5,000 times the diameter, in practice the formula may be written thus:—

$$10)\quad s = \sqrt{2 g \frac{f \left(\frac{p_1 + p_2}{2 p_1}\right)^{\frac{1}{n}}}{\xi \frac{l}{d} w}} \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{feet per sec.};$$

or numerical constants inserted for lead tubes:

$$11) \quad s = 56 \cdot 7 \left(\frac{d}{l}\right)^{\frac{1}{2}} \left(\frac{f}{w}\right)^{\frac{1}{2}} \left(\frac{p_1 + p_2}{2\,p_1}\right)^{\frac{1}{2n}} \quad . \quad . \quad . \quad \text{feet per sec.}$$

[log. $56 \cdot 7 = 1 \cdot 75375$],

which is equivalent to neglecting altogether acceleration and also friction of the carrier. In other words, for light carriers moving in polished tubes, the air is assumed to move with the same velocity whether a carrier is in the tube or not.

4. Time of Transit.

The time occupied by the carrier in passing from one end to the other is

$$t = \frac{l}{s} \quad . \quad . \quad . \quad \text{seconds;}$$

therefore, for lead tubes,

$$12) \quad t = 0 \cdot 0176 \left(\frac{w}{f}\right)^{\frac{1}{2}} \frac{l^{1 \cdot 5}}{d^{0 \cdot 5}} \left(\frac{2\,p_1}{p_1 + p_2}\right)^{\frac{1}{2n}} \quad . \quad . \quad . \quad . \quad \text{seconds.}$$

[log. $0 \cdot 0176 = \bar{2} \cdot 24625$].

5. Mean Weight of a Cubic Foot of Air.

The weight of a cubic foot of air at 20° cent. is 0·07533 lb. at mean barometric pressure.

If the pressure p_1 lbs. per square inch acting on a body of air, each cubic foot of which weighs w_1 lbs., be suddenly changed to p_2 lbs., the weight of a cubic foot will be changed to w_2 lbs.

$$13) \quad w_2 = w_1 \left(\frac{p_2}{p_1}\right)^{\frac{1}{n}} \quad . \quad . \quad . \quad . \quad \text{lbs.}$$

If before the transit of a carrier the pressure at each point in a tube corresponds with the flow of air due to the end pressures, as in continuous working, and if during the transit the latter are kept constant, the mean specific weight (w) of all the air may be assumed to be practically

$$14) \quad w = \frac{w_1 + w_2}{2} \quad . \quad . \quad . \quad . \quad \text{lbs.}$$

But if, as in intermittent working, the tube, to begin with, be filled with air at atmospheric pressure, the mean will be lower or higher than the mean corresponding with the end pressures, according as

the tube is worked with pressure or with vacuum. For pressure-working the mean specific weight may be then taken as

$$15) \quad w = \frac{w_1 + 3\,w_2}{4} \quad . \quad . \quad . \quad . \quad \text{lbs.}$$

For vacuum-working,

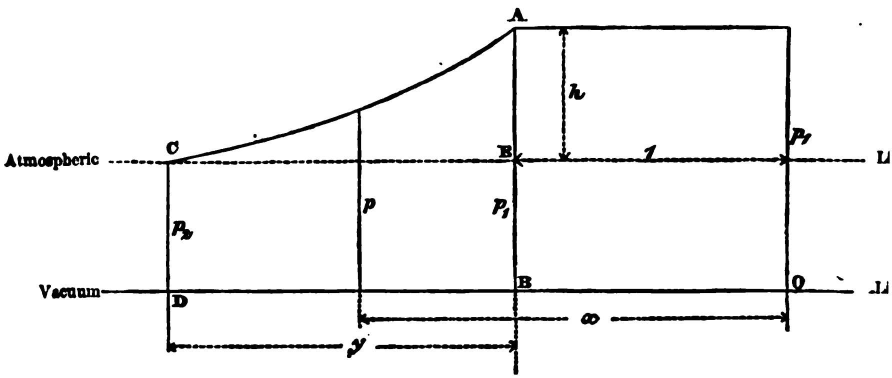
$$16) \quad w = \frac{3\,w_1 + w_2}{4} \quad . \quad . \quad . \quad . \quad \text{lbs.}$$

These mean values it should be understood are only approximations, the actual specific weights being affected to a great extent by accidental causes, such as the temperature of the tube, the resistance offered by curves, &c.

6. Work done in maintaining Compressed Air in the Main or Container.

Let the stroke of the piston of the pressure-pump be from D to O; let the pressure of the atmosphere with which the cylinder is filled at the commencement of the stroke be p_2; let the required effective

Fig. 2.



pressure h (actual pressure $= h + p_2 = p_1$) be reached when the piston arrives at B; and let the piston, in travelling the remaining distance B O, transfer the compressed air from the cylinder into the container.

The air at the commencement of the stroke is already compressed to what is called "atmospheric pressure," therefore each cubic foot already contains a certain potential energy, which is the work it would exert fully if expanded into an absolute vacuum.

When the air is further compressed its potential energy is increased, and the difference between the two potentials is the work it can perform in expanding between the two pressures. This

difference of potentials, or aeromotive power, is represented by the area A B D C, of which the area B D C E has been done by the superincumbent atmosphere, and must be subtracted from the whole energy of the unit volume of compressed air between the two pressures, in order to find the effective energy which the compression costs. In other words, when a cubic foot of compressed air has been produced by a pump, the pump has not done all the work which is stored up in it, because the greater part of this work has usually been done by the pressure of the atmosphere.

The absolute work (F) is represented by the area A B D C.

The effective work by the area ABDC − BDCE = AEC.

The absolute work (F) is, by formula (1),

$$F = \frac{p_1}{n-1}\left\{1 - \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}\right\} \quad . \ . \ . \quad \text{foot lbs.};$$

and since

$$p_2\left(y+1\right)^n = p_1,$$

the length

$$y = \left\{\left(\frac{p_1}{p_2}\right)^{\frac{1}{n}} - 1\right\},$$

and the area EBDC; the work done by the atmosphere is

$$yp_2 = \left\{\left(\frac{p_1}{p_2}\right)^{\frac{1}{n}} - 1\right\}p_2.$$

Therefore the effective work done in compression by the pump is

$$17)\quad F - yp_2 = \frac{p_1}{n-1}\left\{1 - \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}\right\} - \left\{\left(\frac{p_1}{p_2}\right)^{\frac{1}{n}} - 1\right\}p_2.$$

Now this difference is the work which has been performed in driving the piston only to the point B, that is to say, until the air has reached the required pressure p_1. It has still, however, to be driven into the container, and to do this the force h lbs. must be exerted through the distance 1.

For each cubic foot of compressed air, therefore,

the absolute work done (f) is :—

$$f = 144\left[\frac{p_1}{n-1}\left\{1 - \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}\right\}\right] \quad . \ . \ . \quad \text{foot lbs.}$$

The work done by the atmosphere $= a = 144\left\{\left(\frac{p_1}{p_2}\right)^{\frac{1}{n}} - 1\right\}p_2$ foot lbs.

Difference of these = the effective work done in compressing ($f-a$).

Work done in driving compressed air into container = 144 h.

Total amount of effective work, E, done after forcing into the main 1 cubic foot of compressed air =

$$E = f - a + 144\,h \quad . \quad . \quad . \quad \text{foot lbs.,}$$

or,

$$18) \quad E = 144\left[\frac{p_1}{n-1}\left\{1 - \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}\right\} - \left\{\left(\frac{p_1}{p_2}\right)^{\frac{1}{n}} - 1\right\} p_2 + h\right];$$

with the numerical values of constants inserted—

$$353\,p_1\left\{1 - \left(\frac{14 \cdot 75}{p_1}\right)^{\cdot 29}\right\} - 2124\left\{\left(\frac{p_1}{14 \cdot 75}\right)^{\cdot 71} - 1\right\} + 144\,h \text{ foot lbs.}$$

The engine power required for each cubic foot, per minute, of compressed air maintained in the main or container at an actual pressure p_1 is therefore

$$\frac{f - a + 144\,h}{33000} \quad . \quad . \quad . \quad \text{HP.}$$

If in a tube (whose diameter is d feet) the mean speed of a carrier is s feet per second, the volume of compressed air required per minute will be

$$19) \quad 0 \cdot 7854\,d^2 \times 60\,s \times \left(\frac{p_1 + p_2}{2\,p_1}\right)^{\frac{1}{n}}. \quad . \quad . \quad \text{cubic feet.}$$

And the engine power required to do this is

$$20) \quad \frac{f - a + 144\,h}{33000} \times (0 \cdot 7854\,d^2 \times 60\,s) \times \left(\frac{p_1 + p_2}{2\,p_1}\right)^{\frac{1}{n}} \quad . \quad . \quad \text{HP.}$$

7. Work done in taking Rarefied Air out of the Main or Container.

The operations of the vacuum-pump are similar. When the air in the main has once arrived at the state of rarefaction at which it is employed, the lines connected with it admit a continued flow of air, which expands as it comes along the tubes, and enters the pump with nearly the larger bulk due to its diminished pressure. The problem, therefore, resolves itself into compressing this expanded air again to the pressure of the atmosphere, and delivering from the pump the same weight of air per minute as that which under atmospheric pressure enters the tubes at their farther ends.

The effective work, E′, required for each cubic foot per minute of air entering at atmospheric pressure is therefore

$$E' = 144\left[36 \cdot 1\left\{1 - \left(\frac{p_2}{14 \cdot 7}\right)^{\cdot 29}\right\} - p_2\left\{\left(\frac{14 \cdot 7}{p_2}\right)^{\cdot 71} - 1\right\} + h\right] \;.\;.\; \text{ft. lbs.}$$

If the mean speed of a carrier is s feet per second in a tube whose diameter is d feet, the volume of atmospheric air per minute admitted at the farther end is

$$V_1 = 0 \cdot 7854\, d^2 \times 60\, s \times \left(\frac{p_1 + p_2}{2 p_1}\right)^{\frac{1}{n}} \quad . \quad . \quad . \quad \text{cubic feet.}$$

The engine power required per minute for this tube is therefore

$$\frac{E' \times V_1}{33000} \quad . \quad . \quad . \quad \text{HP.}$$

and the engine power calculated from the volume of expanded air is

$$22) \quad \frac{E'\, V_2 \left(\frac{p_2}{14 \cdot 7}\right)^{\cdot 71}}{33000} \quad . \quad . \quad . \quad . \quad \text{HP.}$$

The volume per minute, at the effective vacuum h (actual pressure p_2), as it passes through the main and the vacuum-pump, on the asumption that it does not become heated from contact with the tube, being

$$V_2 = 0 \cdot 7854\, d^2 \times 60\, s \times \left(\frac{p_1 + p_2}{2 p_2}\right)^{\frac{1}{n}} \quad . \quad . \quad . \quad \text{cubic feet.}$$

PART III.

OBSERVATIONS AND RESULTS.

1. Observations of Transit Times.

The experiments which the Authors are enabled to submit are not numerous, because the difficulty of carrying them out was very great. No experiment could be made until the tubes had been brought into use for traffic, and this is so pressing that there is practically no interval of rest, either at night or on Sundays. The times of transit through some of the tubes were observed during actual day service, but it was impossible to maintain constant pressures in all cases on account of the variable traffic; and, moreover, as the carriers themselves differed much in fit, as they were more or less worn, it was feared that, even had steady pressures been attainable, these observations might not have been sufficiently correct. During the night, however, fewer tubes are

in action, and it was found that the air-pressure could be kept approximately steady by allowing the safety valves of the mains to blow off freely, and by opening one or more additional tubes when the mercury of the manometer rose.

By these means, with great care, the manometer indications were maintained within a maximum deviation of $\frac{1}{4}$ lb. per square inch. Special carriers of soft felt were provided, and the times were in some cases recorded electrically and automatically on a paper ribbon, side by side with second beats of a good clock, so that the times could be read off to tenths of seconds, if necessary.[1]

The tubes experimented upon in this exact manner were the Central-Cannon Street, Thames Street (1,841 yards long), and the pair of tubes Central-Fenchurch Street (each 1,409 yards long). The last were connected at Fenchurch Street by a well-fitted curved tube, so that carriers could be sent from Central Station back to Central Station again, through a total length of 2,818 yards; and from the Central Station to Ludgate Circus.

In the experiments on the Cannon Street and Thames Street tube, and also in those on the looped Fenchurch Street tubes, the pressures at the ends and the middles of the tubes were recorded at the start of each carrier, and at each following fifteen seconds, by marking the height of the mercury on paper scales divided into inches and fixed to the gauges. The marks were numbered consecutively, and a fresh scale was used for each journey. This method rendered the observations mechanical, and by giving the observers less to think about, prevented error. By "continuous flow of air" is meant that the communication with the air-main was opened, and the current fully established before the carrier was put in the tube; and by "intermittent flow of air" is meant that the air in the tube was stationary at atmospheric pressure when the carrier was inserted, and that the air-valve was opened afterwards. The gauges fixed just inside the open ends of the tubes at the distant stations were observed to stand steadily at zero throughout the experiments.

So far as these experiments go they serve to show conclusively that the formulæ adopted by the Authors lead to a practically correct result.

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[1] The Authors have been greatly indebted to the energy and care of Mr. Willmot, of the General Post Office, who was kind enough to carry out the experiments for them, and without whose valuable aid it would have been impossible for them to have obtained so complete a series of observations of transit times.

TABLE A.—CENTRAL STATION, CANNON STREET, AND THAMES STREET.

Length = 5,523 feet; diam. = 0·1823 foot.

Manometer at		Flow of Air.	Transit Times between			
			Central Station and Thames Street, 5,523 feet.		Cannon Street and Thames Street, 2,648 feet.	
Central Station.	Cannon Street.		Obs.	Calcul.	Obs.	Calcul.
lbs.	lbs.		Sec.	Sec.	Sec.	Sec.
		PRESSURE.				
8·06	4·43	Continuous	175	179	73	
			175	179	74	
8·12	4·43	do.	175	175	73	76
8·17	4·43	do.	178	174	74	
8·36	4·43	do.	172	173	72	
		VACUUM.				
5·68	1·32	Continuous	185	181	119	128
5·92	1·5	do.	181	175	118	122
6·15	1·32	do.	175	173	112	128
7·92	3·20	do.	144	149	84	
8·0	3·2	do.	145	149	83	82
8·1	3·2	do.	144	148	84	
8·81	3·2	do.	144	142	83	
5·83	1·32	Intermittent	191	185	128	133
	1·42	do.	190	185	127	128
	1·32	do.	194	185	129	133
	1·42	do.	192	185	128	128

TABLE B.—CENTRAL STATION AND FENCHURCH STREET.

Length = 4,227 feet; diam. = 0·1823 foot.

Manometer at Central Station.	Flow of Air.	Transit Times.	
		Obs.	Calcul.
		Sec.	Sec.
Pressure 8·12 lbs.	Continuous	121	117
Do. 8·5 „	do.	114	115
Do. 8·63 „	do.	114	114
Do. 8·75 „	do.	114	113
Do. 9 „	do.	112	112
Do. 9·37 „	do.	113	111
Do. 7·2 „	Intermittent	116	119
		118	
Do. 7·4 „	do.	117	117
Do. 7·6 „	do.	118	116
		116	

TABLE B—*continued.*

Manometer at Central Station.	Flow of Air.	Transit Times.	
		Obs.	Calcul.
		Sec.	Sec.
Pressure 7·7 lbs.	Intermittent.	116 118 109	115
Do. 7·9 „	do.	115 110 114	114
Do. 8 „	do.	118 107 106 109	114
Do. 8·1 „	do.	115 109	114
Do. 8·63 „	do.	102	109
Do. 9·25 „	do.	107	106

TABLE C.—CENTRAL STATION TO LUDGATE CIRCUS.
Length = 2,331 feet; diam. = 0·1823 foot.

Manometer at Central Station.	Flow of Air.	Transit Times.	
		Obs.	Calcul.
		Sec.	Sec.
Pressure, 4·5 lbs. . .	Intermittent	59	61
Do. 5·25 „ . .	do.	55 55 57 57 59	57
Do. 5·5 „ . .	do.	55 57 58 57 55	56
Do. 6 „ . .	..	55	53
Vacuum 3·5 „ . .	Continuous	58	64
Do. 4 „ . .	do.	60 52 55	60
Do. 4·25 „ . .	do.	58 58	58
Do. 4·5 „ . .	do.	58 55 50 53	56
Do. 4·75 „ . .	do.	54 56	55

TABLE D.—MEANS OF SEVERAL OBSERVATIONS MADE DURING ORDINARY TRAFFIC.

Tube between Central Station and	Length.	Manometer at Central Station.	Flow of Air.	Transit Times in Seconds.	
				Observed.	Calculated.
	Feet.				
1. Thames Street	5,528	8 lbs. Pressure	Continuous	175	176
2. Ditto	..	8 „ Vacuum	Do.	145	142
Ditto	..	5·8 „ do.	Intermittent.	190	183
3. Mark Lane	4,923	6·5 „ Pressure	Continuous	178	169
Ditto	..	6·5 „ do.	Intermittent.	159	158
Ditto	..	6·5 „ Vacuum	Continuous	140	138
Ditto	..	6·5 „ do.	Intermittent.	152	144
4. Fenchurch Street	4,227	8·13 „ Pressure	Continuous	121	117
Ditto	..	8·12 „ do.	Intermittent.	112	112
5. Ditto	..	6·25 „ Vacuum	Continuous	108	112
Ditto	..	6·25 „ do.	Intermittent.	121	117
6. Eastcheap	4,014	8·5 „ Pressure	Continuous	106	106
Ditto	..	8·5 „ do.	Intermittent.	102	102
Ditto	..	5·25 „ Vacuum	Continuous	118	116
Ditto	..	5·25 „ do.	Intermittent.	120	119
7. Gresham House	3,867	7·5 „ Pressure	Do.	106	103
Ditto	..	10·5 „ do.	Do.	89	87
8. Ditto	..	5·25 „ Vacuum	Do.	114	113
Ditto	..	5·25 „ do.	Continuous	108	109
9. Leadenhall Street	3,690	5·75 „ Pressure	Intermittent.	106	106
10. Baltic Coffee House	3,576	5·5 „ do.	Do.	107	108
Ditto	..	5·5 „ do.	Continuous	104	106
11. Cornhill	2,895	7·5 „ do.	Intermittent.	63	66
Ditto	..	5·5 „ Vacuum	Continuous	67	69
12. Cannon Street	2,875	6·5 „ Pressure	Intermittent.	65	69
13. Ditto	..	5 „ Vacuum	Do.	74	72
14. Lloyd's	2,862	7 „ Pressure	Do.	66	67
Ditto	..	5·5 „ Vacuum	Continuous	70	69
15. Telegraph Street	2,751	8 „ Pressure	Intermittent.	58	60
Ditto	..	5·25 „ Vacuum	Continuous	68	66
16. Founder's Court	2,424	6 „ Pressure	Intermittent.	58	57
Ditto	..	5·5 „ Vacuum	Continuous	54	53
17. Ludgate Circus	2,331	4·5 „ Pressure	Intermittent.	59	61
Ditto	..	4·5 „ Vacuum	Continuous	54	55

2. IRREGULAR EXPANSION OF AIR IN TUBES.

From experiments made on tubes furnished with gauges at the ends and in the middles, it would appear that the pressure in a tube does not fall regularly with the length, but in the first half in a lesser, and in the second half in a greater ratio. The cause of this is probably to be sought, partly in the inertia of the air, and partly in the resistance offered to its motion by the sides of the tube.

A volume of gas, if it can be imagined for a moment to have an infinitely small inertia, and to move between two constant

pressures through a tube offering infinitely small frictional resistance, would expand uniformly from the volume due to the higher, to the volume due to the lower pressure. During the passage it would have to push onwards the continually increasing bulk of air in front; and not only that, but to continually accelerate it into quicker motion. This it would do uniformly in virtue of the absence of resistance. But in an actual tube, the resistance and the inertia of the air increase with the velocity of its passage; and therefore the resistance which a given volume of compressed air meets in passing through the sending end of a tube is less than it meets with when it reaches the more rarefied state at the delivering end. In a word, it seems that the air as it passes through grows so quickly in bulk that it cannot get out of the way fast enough to make room for the denser air which enters behind. Therefore the mean of the pressures in any tube through which air is flowing is higher than the mean of the pressures at the ends. This is the case, of course, both in pressure and vacuum working; the middle of the tube showing a higher pressure than corresponds with the end pressures. The mean pressure is displaced towards the end of the tube at which the pressure is lowest, and the amount of this displacement, increasing in some ratio with the length of the tube and with the velocity of the air, is much more observable in vacuum than in pressure working, probably because in vacuum-working expansion is greater for equal manometer indications. As an instance: gauges put at the ends and middle of the looped tubes between Fenchurch Street and the Central Station, a total length of 2,818 yards, the pressures observed were as follows:—

	Manometer. Inches of Vacuum.	Actual Pressure. Inches.
Central Station	14·25	15·75
Fenchurch Street . . .	5·75	24·25
Central Station	0·00	30·00

The observed middle pressure being $5\frac{3}{4}$ lbs. instead of $7\frac{1}{8}$ lbs., which would be the mean of the end manometer indications.

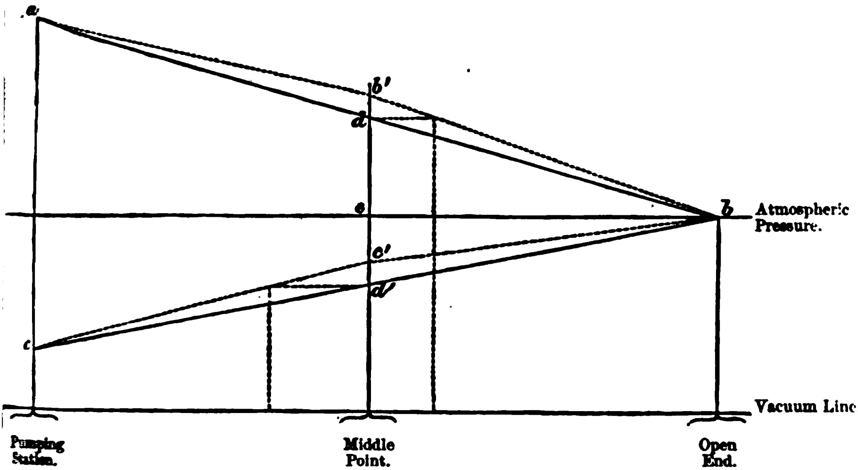
With pressure in the same tube, the manometer indications observed were as follows:—

	Inches of Pressure.		Actual Pressure. Inches.
Central Station	18·00	means of several readings.	48·00
Fenchurch Street . . .	9·75		39·75
Central Station	0·00		30·00

In which the observed middle pressure was $9\frac{3}{4}$ inches instead of 9 inches the mean of the end pressures.

This effect is shown graphically in Fig. 3,

FIG. 3.



the diagonal lines *a d b* and *b d'c* showing a regular fall for pressure and for vacuum working, whereas the actual pressures are shown by the dotted lines *a b'b* and *b c'c*. In pressure-working the manometer indication at the middle station is *b'e* instead of *d e*; and in vacuum-working it is *c'e* instead of *d'e*.

Nearly one hundred observations were made, the tubes being provided with intermediate manometers by which during the flow of air, the pressures at stated intervals were recorded. It was found that in every case the same phenomenon of a higher actual pressure at the intermediate station than that due to its position was observable. And this was found to be true not only for the pneumatic tubes, but likewise for small gas-pipe in various points of which manometers were inserted.

3. EFFECT OF INTERMITTENT WORKING ON THE MANOMETER.

The effect of the air which is in the tube at the commencement of a transmission by intermittent working is very marked upon the manometer gauge of the pumping station. In pressure-working, the tube is filled with air lighter than that due to mean working pressure, therefore until this has been driven forward and a regular fall of density established, the manometer at the sending end records a more sudden fall between the main and the tube than it does after a minute or so. In the same way, with vacuum-working, the tube at commencing being filled with atmospheric air which is heavier than the mean of the working densities, pours

an abundance into the vacuum main at starting, and thus keeps down the indication of the vacuum gauge.

Some observations on this point are given in the following table of manometer indications in inches of mercury, in the tubes between Central Station and Thames Street (1,841 yards).

Times after opening Valve.	Pressure.				Vacuum.						
	1	2	3	4	1	2	3	4	5	6	7
15 sec.	14·5	13·7	11·5	12·4	9·5	9·0	11·0	10·5	9·7	9·6	9·0
30 "	16·5	14·7	12·7	13·0	..	..	11·5	11·7	4·5	11·5	9·2
45 "	17·0	15·0	13·0	13·2	..	..	11·7	12·0	12·0	11·9	..
60 "	..	15·2	..	..	..	9·6	12·0	..	..	12·1	..
75 "	..	15·7	..	..	9·7	9·7	..	..	..	..	..
90 "	..	16·2	..	..	..	..	..	..	..	..	9·5
105 "	..	16·5	..	..	..	..	..	12·2	12·2	..	9·7
120 "	..	16·7	13·2	..	..	..	..	..	..	..	..
135 "	..	17·2	..	..	..	..	..	..	..	..	10·0
150 "	17·2	..	..	..	..	10·2	..	..	..	..	..
165 "	..	..	..	..	..	..	12·2	..	..	..	..
180 "	..	..	..	..	..	..	..	..	..	..	..

From this it is seen that about three-quarters of a minute are required with intermittent working before the gauge at the end of the tube at the pumping station shows an indication corresponding with the nearly regular fall of pressure established whilst the air is steadily flowing through. At the middle of the tube this is also observable, only it takes, on the Central and Thames Street tube, nearly one minute and a quarter for the mean pressure to be reached at Cannon Street.

4. Observations of the Temperature of Air in the Tube.

When a volume of air at the pressure p_2 lbs. per square inch, at a temperature $t_2°$ cent. is suddenly subjected to any other pressures, p_1, its temperature is changed to $t_1°$ cent.

$$t_1 = (273 + t_2^{\circ}) \left(\frac{p_1}{p_2}\right)^{\frac{n-1}{n}} - 273 \quad . \quad . \quad . \quad \text{deg. cent.}$$

Thus, if air under atmospheric pressure (14·75 lbs.) at 20° cent. were suddenly compressed to 10 lbs. effective pressure its temperature would be raised to about 67° cent. And if air at atmospheric pressure at 20° cent. is suddenly expanded to 10 lbs. effective vacuum its temperature is reduced to −20° cent. But when the expansion takes place gradually through the length of a metal tube

the air has a tendency to increase in temperature both by friction and by conduction.

Some observations were made on the temperatures of different tubes, the results of which were very various. Generally, however, the temperature of the air in issuing is lower than on entering a tube, but not to the extent corresponding with its expansion. As an instance, the following observation at different points of the Cannon Street tube showed that the actual fall of temperature through the expansion is from these causes rendered comparatively little.

Working.	Central Station.		Cannon Street.	Thames Street.	
	Observed.	Calculated.	Observed.	Observed.	Calculated.
	Deg. Cent.	Deg. Cent.	Deg. Cent.	Deg. Cent.	Deg. Cent.
Temp. of air in pressure pipe (8·6 lbs.)	26°·6	° ..	10°·0	13°·8	−11°·2
Temp. of office from which the air was drawn	17·7	..	15·5	15·5	..
Temp. of air in vacuum pipe (6·4 lbs.)	13·3	−30·4	12·7	13·3	..

Thus in the pressure experiment, instead of the air arriving at the Thames Street Station at $-11°\cdot2$ cent., it actually arrived with a temperature of $+13°\cdot8$, in other words, that the difference (25° cent.) had been gained on the way. In the same way, in the vacuum experiment, the air which entered the tube from the office at 15°·5 cent. had when it passed the thermometer close to the mouth a temperature of only 13°·3 cent., and this, instead of arriving at the Central Station with the temperature $-30°\cdot4$, that is, about 44° cent. below that at which it started, had really only fallen to 13°·3 cent., or precisely the same temperature as immediately after entering the tube. It is probably due to this behaviour of the air in tubes that Redtenbacher and others have in their formulæ assumed the expansion to be necessarily isothermal.

In the pneumatic tubes in Berlin, which form a closed circuit, where they cross the canal bridge intermediate between the two stations, the pressure tube is sensibly warmer, while the vacuum tube is colder, than the atmosphere. The difference between this behaviour and that of the tubes in London, which appear to retain an equal temperature throughout, is probably due to the dampness of the London soil, the tubes in Berlin lying mostly in

dry sand, which insulates them, and this enables them to acquire and retain the temperature of the included air.

5. Experiments on Leakage.

The nature of the joints between the several lengths of lead tubes precludes the possibility of leakage through them. The valves and other connections at the stations are, however, always to some extent liable to leakage.

On the tubes between the Central Station and Thames Street (1,841 yards) the following experiment was made:—The Thames Street end of the vacuum tube was closely stopped, whilst the switches at Cannon Street were also made air-tight. The Central Station end of the tube was then placed in connection with the vacuum main for a few minutes, after which the valve was shut off and the fall of the manometer due to leakage observed from minute to minute.

After cutting off. — Minutes.	Manometer. — Inches of Mercury.	After cutting off. — Minutes.	Manometer. — Inches of Mercury.
0	18	10	$9\frac{3}{4}$
1	17	11	$8\frac{3}{4}$
2	15	12	$7\frac{3}{4}$
3	$14\frac{1}{2}$	13	7
4	14	14	6
5	$13\frac{1}{2}$	15	5
6	$12\frac{1}{2}$	16	4
7	$12\frac{1}{4}$	17	$3\frac{1}{2}$
8	11	18	$2\frac{1}{2}$
9	$10\frac{1}{2}$	19	$2\frac{4}{10}$

On the Gresham House tube (1,289 yards), the distant end being plugged, the tube completely recovered atmospheric pressure in thirteen minutes as follows:—

After cutting off. — Minutes.	Manometer. — Inches of Mercury.	After cutting off. — Minutes.	Manometer. — Inches of Mercury.
0	$17\frac{1}{4}$	7	$5\frac{1}{2}$
1	$15\frac{1}{2}$	8	4
2	$13\frac{3}{4}$	9	$2\frac{1}{2}$
3	12	10	$1\frac{1}{2}$
4	10	11	$\frac{3}{4}$
5	$8\frac{1}{2}$	12	$\frac{1}{2}$
6	7	13	0

The same tube with a screw $\frac{1}{8}$ inch in diameter taken out of the valve at the Central Station recovered atmospheric pressure in half the time given as above.

Pressures best suited for Working.

In order to know what engine power has to be provided, it is first of all requisite to determine what effective pressures and vacua should be used in working the tubes. Experiment as well as theory show that with vacuum-working, the weight of air to be moved being much less than with pressure-working, the speed of a carrier with any given effective pressure would be considerably less than that with a corresponding effective vacuum. In the following table the effective pressures and vacua which would bring a carrier through in equal times under continuous working are placed side by side:—

Effective Pressure.	Equivalent Effective Vacuum.	Effective Pressure.	Equivalent Effective Vacuum.
lbs. per sq. in.	lbs. per sq. in.	lbs. per sq. in.	lbs. per sq. in.
3	2·6	10	6·7
4	3·3	11	7·1
5	4·0	12	7·5
6	4·6	13	8·3
7	5·3	14	8·5
8	5·7	15	9·0
9	6·3		

With a pressure of 10 lbs. per square inch, working continuously, carriers can be transmitted through lead tubes of 1,000, 2,000, and 3,000 yards in the times and with the HP. shown in the following table:—

Length.	2¼-inch Lead Tubes.			3-inch Lead Tubes.		
	Times of Transit.	Volume of Compressed Air per Minute.	HP.	Times of Transit.	Volume of Compressed Air per Minute.	HP.
Yards.	Min. Sec.	Cubic Feet.		Min. Sec.	Cubic Feet.	
1,000	0 63	67	3·5	0 55	139	7·1
2,000	2 58	48	2·5	2 34	98	5·1
3,000	5 27	39	2·0	4 43	79	4·1

And with a pressure of 5 lbs. with the same lengths and tubes:

1,000	1 26	53	1·3	1 14	107	2·6
2,000	4 1	37	0·9	3 30	79	1·9
3,000	7 24	29	0·7	6 26	62	1·5

From these tables it is apparent that, with equal lengths and equal pressures, the speed obtained in a 3-inch tube is only about 16 per cent. higher than that in a 2¼-inch, whilst an engine power more than double is expended upon it. Obviously, therefore, any increase of diameter above that actually necessary to fulfil the requirements of the service is attended with a very serious expenditure.

By employing 10 lbs. instead of 5 lbs. and thus doubling the pressure, the saving is only 30 per cent. of the time of transit. But by doubling the pressure the volume of compressed air is increased by 30 per cent., and this increased volume consists of air at double the pressure, which costs more engine power to produce. Now in order to produce per minute 1,000 cubic feet of compressed air, and to force the same into a container, the utilised engine performance is

24·1 HP. when the air is compressed, 5 lbs.
51·9 HP. ditto ditto 10 lbs.

Raising the pressure from 5 lbs. to 10 lbs., therefore, would increase at the same time the engine power, as appears by the tables, from 1·3 to 3·5 HP. for the 2¼-inch tube, and from 2·6 to 7·1 HP. for the 3-inch tube. So that in saving, by double pressure, 30 per cent. of the time of transit, an engine nearly three times as powerful would be required. It is obvious, therefore, that pneumatic tubes should be worked with as low a pressure as is practicable, and that if the time of transit is required to be lessened, it is advisable to increase the pressure rather than to increase the diameter in designing a line of given length. This may be more clearly seen by a direct comparison of the two tubes, which have already served as examples. The 3-inch tube being worked with 5 lbs., and the 2¼-inch with 7 lbs. pressure, would give very nearly equal times of transit, and the volume of air and HP. would be as follows:—

Length.	2¼-inch Lead Tubes (7 lbs. Pressure).			3-inch Lead Tubes (5 lbs. Pressure).		
	Times of Transit.	Volume of Compressed Air per Minute.	HP.	Times of Transit.	Volume of Compressed Air per Minute.	HP.
Yards.	Min. Sec.	Cubic Feet.		Min. Sec.	Cubic Feet.	
1,000	1 14	60	2·1	1 14	107	2·6
2,000	3 30	42	1·5	3 30	79	1·9
3,000	6 21	35	1·2	6 26	62	1·5

Therefore, in two lead tubes of equal length, one 3 inches and the other 2¼ inches in diameter, by employing 5 lbs. to work the 3-inch tube, and 7 lbs. to work the 2¼-inch, about the same speed of transit obtains in both, and in the smaller tube with the higher pressure considerably less HP. is expended. Hence if the carriers of the 2¼-inch tube are sufficiently capacious for the traffic, the economy resulting from the employment of that size is obvious.

Relative Economy of Pressure and Vacuum Working.

With any given tube it has been shown that a smaller manometer indication of vacuum is necessary than of pressure in order to transmit a carrier in a given time, and the question naturally suggests itself whether, when the transit time is given, pressure or vacuum working is the cheaper. Practically the question would arise (in the event of any line being required for traffic in one direction only) at which end of the tube the pumping machinery should be placed.

With pressure-working the compression takes place entirely in the pump, the air entering the main with a high temperature, which it loses to a great extent before it enters the tube, the temperature of which it more or less nearly assumes. With vacuum-working, the expansion takes place almost wholly in the tube, whose temperature the air assumes approximately as it passes along. The volume of the rarefied air, therefore, which has to pass through the vacuum pump is greater than it would be if all the expansion took place in the pump by so much as is due to its higher temperature.

The following table gives the volume of compressed and rarefied air which would transmit a carrier in equal times through a 2¼-inch tube 5,000 feet long, together with the HP. requisite.

Effective Pressure.	Equivalent Effective Vacuum.	Transit Times.	Volumes of Air per minute.		HP. during Transit.	
			Compressed for Pressure-working.	Rarefied for Vacuum-working.	For Pressure.	For Vacuum.
lbs.	lbs.	Sec.	Cubic Feet.	Cubic Feet.		
6	4·6	170	41	59	1·18	1·06
9	6·3	142	47	60	2·18	1·78
12	7·7	126	52	91	3·31	2·28

It will be seen by the last two columns that the HP. consumed

is greater when pressure than when vacuum is used to transmit a carrier in a given time, and that in so far as the consumption of coal is concerned it would be therefore advantageous to place the pumping machinery at the receiving end. Practically, however, this has not been confirmed by the Post Office tubes.

Relative Value of Intermittent and Continuous Working.

In the intermittent system the air which is stationary in the tube immediately before the transit begins has each time to be accelerated; whereas in the continuous and closed-circuit systems, the air being already in motion, the loss of time required to do this is avoided. In practice, however, it is found that the work required for the acceleration of the air is so small, in comparison with that employed in overcoming its friction against the sides of the tubes, that it may be neglected. With any given tube, other things being equal, the time which a carrier takes in transit is directly proportional to the square root of the mean weight of the air, not only that which was in the tube at the beginning, but that which is in it at the moment the carrier arrives; in a word, it is proportional to the square root of the mean weight of all the air which has to be put into motion. When air is flowing through a tube between two constant pressures, the density at points along the length decreases nearly regularly from the higher pressure at one end to the lower pressure at the other. Accordingly, in continuous working with compressed air, the density, and therefore the weight, of the air in the tube is greater at the moment the carrier is inserted than it would be if the air in the tube were uniformly at starting at atmospheric pressure, as in intermittent working; and as a consequence the speed of a carrier driven by compressed air is greater with intermittent than with continuous working.

The higher the effective pressure employed, the greater is the difference in speed due to this cause. With 6 lbs. effective pressure, for example, a carrier takes only 3 per cent. longer time with continuous than with intermittent working, whereas with 14 lbs. effective pressure it takes nearly 6 per cent. longer time.

The following table gives the percentage of time that would be lost in transit by using the continuous instead of intermittent system for compressed air.

Effective Pressure per Square Inch.	Extra Transit Time beyond that occupied with Intermittent System.	Effective Pressure per Square Inch.	Extra Transit Time beyond that occupied with Intermittent Systems.
lbs.	Per Cent.	lbs.	Per Cent.
6	3·1	11	4·7
7	3·6	12	5·0
8	3·9	13	5·4
9	4·2	14	5·7
10	4·5		

As a rule it is less advisable to use the continuous than the intermittent system for sending with compressed air.

In continuous working with rarefied air the reverse is the case; for if the transit is commenced with air at atmospheric pressure in the tube, the mean weight of the air is considerably higher than when the air is flowing through on the continuous system; therefore in vacuum-working the continuous system is the more speedy. For instance, with 3 lbs. effective vacuum, a carrier would take 2 per cent. less time, and with 8 lbs. nearly 6 per cent. less time in transit with continuous than with intermittent working.

The percentage of time gained by vacuum-working with the continuous system is shown in the following table, for different effective vacua:—

Effective Vacua per Square Inch.	Time saved by Continuous System.
lbs.	Per Cent.
3	1·9
4	2·6
5	3·4
6	4·3
7	4·9
8	5·8

As a rule, also, it is more economical in time to use the continuous than the intermittent system for vacuum-working.

On the score of relative engine power consumed, with continuous working there must be intervals between the transmission of carriers when the air still flowing through would be performing no useful work. In a system of tubes having to perform only a limited traffic, the time during which the engine would be performing useless work (unless it were desirable to utilise such intervals to accumulate pressure or vacuum in a container) would be considerable; but in London, where, during the working hours of the day, the tubes are never a moment idle, this consideration is of little practical importance. Where radiating

tubes are employed, pressure should be worked on the intermittent system, vacuum on the continuous system. But where there is an interval of one or two minutes between the journeys, vacuum can be used intermittently without loss of time, if the distant end of the tube be kept closed by a sluice which is opened after the carrier is inserted. The air in the tube is rarefied in the interval, and the carrier starts into a comparatively high vacuum.

The choice between the plan of a closed-circuit system to embrace several stations on the one hand, and the connection of each one with the central station by direct radiating tubes on the other, must always be settled by considering whether the correspondence is to be carried on solely to and from the central station, or whether it is desirable to allow the outlying stations to correspond with each other. The great length of tube in a closed circuit materially lessens the speed of transit, so that the possible saving in the cost of establishment over the radial system would, perhaps, not be compensation for the inefficiency of the service. Against a closed circuit it is also to be urged that advantage cannot be taken of the increased speed due to intermittent working, and therefore that any advantage gained in speed at the vacuum end is lost at the pressure end of the tube.

The communication is accompanied by a series of diagrams, from which Plate 5 has been compiled.

APPENDICES.

APPENDIX I.

TABLES TO FACILITATE THE SOLUTION OF PROBLEMS ARISING IN PNEUMATIC TRANSMISSION.

TABLE I.—PRESSURE.

h. Effective Pressure per Square Inch.	p_1. Actual Pressure per Square Inch. (h + 14·75 lbs.)	f. Work performed by 1 Cubic Foot of Air in expanding from p_1 lbs. to 14·75 lbs.	v_1. Volume of Denser Air which enters Tube during transit.	w_1. Weight of 1 Cubic Foot of Air immediately after compression.	w. Mean Weight of Air per Cubic Foot. Continuous Flow.	Intermittent Flow.
lbs.	lbs.	Foot lbs.	Volume of Tube = 100.	lb.	lb.	lb.
3·00	17·75	328	94·0	·0859	·0806	·0779
3·25	18·00	357	93·5	·0867	·0810	·0781
3·50	18·25	386	93·1	·0876	·0814	·0783
3·75	18·50	415	92·6	·0884	·0819	·0785
4·00	18·75	445	92·2	·0893	·0823	·0788
4·25	19·00	475	91·8	·0901	·0827	·0790
4·50	19·25	505	91·4	·0910	·0831	·0792
4·75	19·50	535	91·0	·0918	·0836	·0794
5·00	19·75	566	90·7	·0926	·0840	·0796
5·25	20·00	597	90·3	·0935	·0844	·0798
5·50	20·25	628	90·0	·0943	·0848	·0800
5·75	20·50	659	89·7	·0951	·0852	·0802
6·00	20·75	690	89·4	·0959	·0856	·0804
6·25	21·00	722	89·2	·0968	·0860	·0806
6·50	21·25	754	88·9	·0976	·0864	·0808
6·75	21·50	786	88·6	·0984	·0868	·0810
7·00	21·75	818	88·3	·0992	·0873	·0812
7·25	22·00	850	88·0	·1000	·0877	·0814
7·50	22·25	883	87·6	·1008	·0881	·0816
7·75	22·50	915	87·3	·1016	·0885	·0818
8·00	22·75	948	87·1	·1024	·0889	·0820
8·25	23·00	981	86·8	·1032	·0893	·0822
8·50	23·25	1,015	86·6	·1040	·0897	·0824
8·75	23·50	1,048	86·3	·1048	·0901	·0826
9·00	23·75	1,081	86·1	·1056	·0905	·0828
9·25	24·00	1,115	85·8	·1064	·0908	·0830
9·50	24·25	1,149	85·6	·1072	·0912	·0832
9·75	24·50	1,183	85·3	·1080	·0916	·0834
10·00	24·75	1,218	85·1	·1087	·0920	·0836
10·25	25·00	1,252	84·8	·1095	·0924	·0838
10·50	25·25	1,287	84·6	·1103	·0928	·0840
10·75	25·50	1,321	84·4	·1111	·0932	·0842
11·00	25·75	1,356	84·2	·1118	·0936	·0844
11·25	26·00	1,391	84·0	·1126	·0939	·0846
11·50	26·25	1,426	83·8	·1134	·0943	·0848
11·75	26·50	1,461	83·6	·1142	·0947	·0850
12·00	26·75	1,497	83·5	·1150	·0951	·0852

TABLE II.—VACUUM.

h. Effective Vacuum per Square Inch.	p_2. Actual Pressure per Square Inch.	f. Work performed by 1 Cubic Foot of Air in expanding from 14·75lbs. to p_2 lbs.	v_1. Volume of Air at Atmospheric Pressure which enters Tube during transit.	w_2. Weight of 1 Cubic Foot of Air immediately after rarefaction.	w. Mean Specific Weight of Air.	
					Continuous Flow.	Intermittent Flow.
lbs.	lbs.	Foot lbs.	Volume of Tube = 100.	lb.	lb.	lb.
3·00	11·75	332	92·6	·0641	·0697	·0725
3·25	11·50	363	92·0	·0631	·0692	·0722
3·50	11·25	393	91·4	·0621	·0687	·0720
3·75	11·00	425	90·8	·0611	·0682	·0717
4·00	10·75	456	90·3	·0602	·0677	·0715
4·25	10·50	489	89·6	·0592	·0672	·0712
4·50	10·25	521	89·0	·0582	·0667	·0710
4·75	10·00	555	88·3	·0571	·0662	·0707
5·00	9·75	589	87·6	·0561	·0657	·0705
5·25	9·50	624	87·0	·0551	·0652	·0702
5·50	9·25	659	86·4	·0541	·0647	·0700
5·75	9·00	695	85·7	·0530	·0642	·0697
6·00	8·75	732	85·1	·0520	·0636	·0694
6·25	8·50	769	84·5	·0509	·0631	·0692
6·50	8·25	807	83·8	·0498	·0626	·0689
6·75	8·00	846	83·2	·0488	·0620	·0686
7·00	7·75	886	82·5	·0477	·0615	·0684
7·25	7·50	927	81·8	·0466	·0609	·0681
7·50	7·25	969	81·2	·0455	·0604	·0678
7·75	7·00	1,012	80·5	·0444	·0598	·0675
8·00	6·75	1,056	79·8	·0432	·0593	·0672
8·25	6·50	1,101	79·3	·0421	·0587	·0670
8·50	6·25	1,148	78·6	·0409	·0581	·0667
8·75	6·00	1,195	77·9	·0398	·0575	·0664
9·00	5·75	1,244	77·3	·0386	·0569	·0661
9·25	5·50	1,295	76·7	·0374	·0563	·0658
9·50	5·25	1,348	76·0	·0362	·0557	·0655
9·75	5·00	1,402	75·3	·0349	·0551	·0652
10·00	4·75	1,458	74·5	·0337	·0545	·0649
10·25	4·50	1,516	73·9	·0324	·0539	·0645
10·50	4·25	1,577	73·1	·0311	·0532	·0642
10·75	4·00	1,640	72·5	·0298	·0526	·0639
11·00	3·75	1,706	71·8	·0285	·0519	·0636
11·25	3·50	1,776	71·1	·0271	·0512	·0632
11·50	3·25	1,849	70·4	·0257	·0505	·0629
11·75	3·00	1,926	69·7	·0243	·0498	·0625
12·00	2·75	2,007	69·0	·0228	·0491	·0621

TABLE III.—DIMENSION-CO-EFFICIENTS (K) PROPORTIONAL TO TRANSIT TIMES WITH SAME PRESSURE OR VACUUM.

Length.		Values of K for			Length.		Values of K for		
Yards.	Feet.	1¼-inch Tube.	2¼-inch Tube.	3-inch Tube.	Yards.	Feet.	1¼-inch Tube.	2¼-inch Tube.	3-inch Tube.
500	1,500	16·4	13·4	11·6	2,000	6,000	131	107	93·0
550	1,650	19·0	15·5	13·4	2,050	6,150	136	111	96·4
600	1,800	21·6	17·6	15·3	2,100	6,300	141	115	100
650	1,950	24·4	19·9	17·2	2,150	6,450	146	120	104
700	2,100	27·2	22·2	19·2	2,200	6,600	152	124	107
750	2,250	30·2	24·7	21·3	2,250	6,750	157	128	111
800	2,400	33·3	27·2	23·5	2,300	6,900	162	132	115
850	2,550	36·3	29·7	25·7	2,350	7,050	167	137	118
900	2,700	39·7	32·4	28·1	2,400	7,200	173	141	122
950	2,850	43·0	35·1	30·5	2,450	7,350	178	146	126
1,000	3,000	46·5	37·9	32·9	2,500	7,500	184	150	130
1,050	3,150	50·0	40·8	35·4	2,550	7,650	189	155	134
1,100	3,300	53·6	43·8	37·9	2,600	7,800	195	159	138
1,150	3,450	57·3	46·8	40·6	2,650	7,950	200	164	142
1,200	3,600	61·1	49·9	43·2	2,700	8,100	206	168	146
1,250	3,750	64·9	53·0	45·9	2,750	8,250	212	173	150
1,300	3,900	68·9	56·2	48·6	2,800	8,400	218	178	154
1,350	4,050	72·9	59·5	51·4	2,850	8,550	224	183	158
1,400	4,200	77·0	62·9	54·4	2,900	8,700	229	187	162
1,450	4,350	81·1	66·3	57·4	2,950	8,850	235	192	166
1,500	4,500	85·4	69·7	60·4	3,000	9,000	241	197	171
1,550	4,650	89·7	73·2	63·4	3,050	9,150	247	202	175
1,600	4,800	94·0	76·8	66·5	3,100	9,300	254	207	179
1,650	4,950	98·5	80·4	69·6	3,150	9,450	260	212	184
1,700	5,100	103	84·1	72·8	3,200	9,600	266	217	188
1,750	5,250	108	87·9	76·1	3,250	9,750	272	222	193
1,800	5,400	112	91·6	79·4	3,300	9,900	279	227	197
1,850	5,550	117	95·5	82·7	3,350	10,050	285	233	202
1,900	5,700	122	99·4	86·1	3,400	10,200	291	238	206
1,950	5,850	126	103	89·5	3,450	10,350	298	243	211

TABLE IV.—NUMBER (φ) PROPORTIONAL TO TIMES OF TRANSIT WITH PRESSURE AND VACUUM.

h. Manometer Indication in lbs. per Square Inch.	Pressure.		Vacuum.	
	φ Continuous Flow.	φ Intermittent Flow.	φ Continuous Flow.	φ Intermittent Flow.
3·00	2·85	2·81	2·66	2·71
3·25	2·75	2·70	2·55	2·61
3·50	2·65	2·62	2·44	2·49
3·75	2·58	2·53	2·35	2·42
4·00	2·50	2·45	2·26	2·32
4·25	2·43	2·38	2·20	2·24
4·50	2·37	2·32	2·11	2·17
4·75	2·31	2·26	2·06	2·11
5·00	2·26	2·21	1·99	2·06
5·25	2·21	2·16	1·94	2·00
5·50	2·17	2·11	1·89	1·95
5·75	2·13	2·06	1·83	1·90
6·00	2·09	2·01	1·78	1·86
6·25	2·05	1·97	1·74	1·82
6·50	2·02	1·94	1·70	1·78
6·75	1·98	1·90	1·66	1·74
7·00	1·95	1·87	1·62	1·71
7·25	1·91	1·84	1·58	1·67
7·50	1·88	1·81	1·55	1·64
7·75	1·85	1·78	1·51	1·60
8·00	1·83	1·76	1·48	1·57
8·25	1·81	1·73	1·45	1·54
8·50	1·78	1·71	1·42	1·52
8·75	1·76	1·68	1·39	1·49
9·00	1·74	1·66	1·36	1·46
9·25	1·72	1·64	1·33	1·43
9·50	1·70	1·62	1·30	1·40
9·75	1·68	1·60	1·28	1·38
10·00	1·66	1·58	1·25	1·36
10·25	1·64	1·56	1·22	1·34
10·50	1·63	1·55	1·20	1·31
10·75	1·61	1·53	1·18	1·29
11·00	1·60	1·52	1·15	1·27
11·25	1·57	1·50	1·13	1·25
11·50	1·56	1·49	1·10	1·23
11·75	1·55	1·47	1·08	1·21
12·00	1·54	1·46	1·06	1·19

TABLES III. AND IV.

The purpose of these tables is to enable the time of transit of a carrier, in a tube of given dimensions with given pressure or vacuum, to be calculated in seconds, by a simple multiplication of the co-efficient (K) (Table III.) with φ (Table IV.).

Some explanation of the manner in which these tables are constructed is necessary.

The formula of the speed of a carrier passing through a lead tube

$$s = 56 \cdot 7 \left(\frac{f}{w}\right)^{\frac{1}{2}} \left(\frac{d}{l}\right)^{\frac{1}{2}} \left(\frac{p_1 + p_2}{2p_1}\right)^{\frac{1}{2n}} \quad . \quad . \quad . \quad \text{feet per second,}$$

may be divided into three parts:—

1st, the numerical constant $56 \cdot 72$;

2nd, the value $\left(\frac{d}{l}\right)^{\frac{1}{2}}$, which contains functions of dimensions only;

3rd, the value $\left(\frac{f}{w}\right)^{\frac{1}{2}} \left(\frac{p_1 + p_2}{2p_1}\right)^{\frac{1}{2n}}$, containing only functions of the pressure or vacuum.

Every effective pressure or vacuum has an individual co-efficient of work $\frac{f}{w}\left(\frac{p_1 + p_2}{2p_2}\right)^{\frac{1}{n}}$, which is brought to bear against the tube resistance, of which the expression is $\left(\frac{l}{d}\right)$, in order to produce a current, the speed of which (s) is the quotient of the square roots of these two values—

$$s = \frac{\left(\frac{f}{w}\right)^{\frac{1}{2}} \left(\frac{p_1 + p_2}{2p_2}\right)^{\frac{1}{2n}}}{\left(\frac{l}{d}\right)^{\frac{1}{2}}} \times 56 \cdot 7 \quad . \quad . \quad . \quad \text{feet per second.}$$

The time of transit through 1 foot is the reciprocal of this, and that through the whole length, l feet, is—

$$t = l \left\{ \frac{\left(\frac{l}{d}\right)^{\frac{1}{2}}}{56 \cdot 7 \left(\frac{f}{w}\right)^{\frac{1}{2}} \left(\frac{p_1 + p_2}{2p_1}\right)^{\frac{1}{2n}}} \right\} \quad . \quad . \quad . \quad \text{seconds,}$$

or

$$t = \cdot 01763 \ \frac{l^{1 \cdot 5}}{d^{0 \cdot 5}} \left(\frac{1}{\frac{f}{w}}\right)^{\frac{1}{2}} \frac{1}{\left(\frac{p_1 + p_2}{2p_1}\right)^{\frac{1}{2n}}} \quad . \quad . \quad . \quad \text{seconds.}$$

Now $\frac{l^{1 \cdot 5}}{d^{0 \cdot 5}}$ (= K) is a co-efficient of dimensions; and any number of tubes which have the same co-efficient of dimensions will, when worked with the same pressure or vacuum, allow a carrier to pass through in the same time, whatever may be their lengths. Thus, if worked with the same pressure, or vacuum, carriers would pass through

3,000 yards of 3-inch tube,
2,730 yards of 2½-inch tube, or
2,380 yards of 1½-inch tube,

in identically the same time; because the co-efficient of dimensions (K) of all these three lengths of pipe is the same (171).

Table III., in which are given, for various lengths, the values of these dimension-co-efficients for the three sizes of lead tubes commonly employed, has

therefore been constructed; the actual co-efficients being multiplied by 10^{-4} in order to save needless figures.

Furthermore, the expression

$$\frac{\cdot 01763}{\left(\frac{f}{w}\right)^{\frac{1}{2}}\left(\frac{p_1+p_2}{2p_1}\right)^{\frac{1}{2n}}}$$

or

$$\cdot 01763\left(\frac{w}{f}\right)^{\frac{1}{2}}\left(\frac{2p_1}{p_1+p_2}\right)^{\frac{1}{2n}}$$

is a co-efficient peculiar to each pressure and to each vacuum.

When this co-efficient for any vacuum is equal to that for some pressure, the pressure in question, worked upon the same tube, sends a carrier through in the same time as the vacuum.

These co-efficients have been arranged in Table IV. for manometer indications of pressure and vacuum between 3 lbs. and 12 lbs. The actual co-efficients, as found by the formula, have been multiplied by 10^4 in order to save needless figures.

Thus it will be found that the co-efficient (ϕ) corresponding to 6¾ lbs. intermittent vacuum (1·74) is the same as that corresponding with 6¼ lbs. continuous vacuum, with 8¼ lbs. intermittent pressure, and with 9 lbs. continuous pressure. This means that, in the same pipe, 6¾ lbs. intermittent vacuum will transmit a carrier through in the same time as 9 lbs. pressure if worked continuously.

The simple multiplication of this co-efficient (ϕ) with the co-efficient of dimensions (K) gives the time in seconds occupied by a carrier in traversing the tube.

For example: 3,000 yards of 3-inch lead tube has a dimension co-efficient (K) = 171, and, if worked intermittently with 11¼ lbs. pressure [the co-efficient (ϕ) of 11¼ lbs. being 1·5], a carrier would take

$171 \times 1\cdot 5 = 256$ seconds, or 4 minutes 16 seconds, to pass through.

TABLE V.—EFFECTIVE PRESSURES AND MEAN VELOCITY.

$$\left(\text{Velocity} = n\sqrt{\frac{d}{l}}\ \text{feet per second.}\right)$$

Manometer Indication in lbs. per Square Inch.	Number (n) proportional to Mean Velocity of Air in Tube working		Manometer Indication in lbs. per Square Inch.	Number (n) proportional to Mean Velocity of Air in Tube working.	
	Continuously.	Intermittently.		Continuously.	Intermittently.
lbs.	$n=$	$n=$	lbs.	$n=$	$n=$
3·00	3,520	3,570	7·75	5,370	5,600
3·25	3,650	3,700	8·00	5,460	5,680
3·50	3,770	3,820	8·25	5,520	5,690
3·75	3,880	3,960	8·50	5,620	5,770
4·00	4,000	4,080	8·75	5,680	5,840
4·25	4,110	4,200	9·00	5,750	6,020
4·50	4,220	4,320	9·25	5,810	6,090
4·75	4,320	4,430	9·50	5,880	6,170
5·00	4,420	4,550	9·75	5,940	6,250
5·25	4,530	4,660	10·00	6,020	6,330
5·50	4,620	4,760	10·25	6,050	6,390
5·75	4,710	4,870	10·50	6,100	6,460
6·00	4,810	4,980	10·75	6,170	6,530
6·25	4,890	5,080	11·00	6,250	6,580
6·50	4,970	5,170	11·25	6,380	6,640
6·75	5,060	5,260	11·50	6,410	6,710
7·00	5,150	5,350	11·75	6,450	6,780
7·25	5,230	5,430	12·00	6,490	6,850
7·50	5,300	5,520	..	..	..

TABLE VI.—EFFECTIVE VACUA AND VELOCITY.

$$\left(\text{Velocity} = n^1 \sqrt{\frac{d}{l}} \text{ feet per second.}\right)$$

Manometer Indication in lbs. per Square Inch.	Number (n^1) proportional to Velocity of Air in Tube working		Manometer Indication in lbs. per Square Inch.	Number (n^1) proportional to Velocity of Air in Tube working	
	Continuously.	Intermittently.		Continuously.	Intermittently.
lbs.	$n^1 =$	$n^1 =$	lbs.	$n^1 =$	$n^1 =$
3·00	3,770	3,690	7·75	6,620	6,250
3·25	3,950	3,850	8·00	6,760	6,370
3·50	4,120	4,000	8·25	6,900	6,490
3·75	4,270	4,150	8·50	7,040	6,580
4·00	4,420	4,310	8·75	7,190	6,710
4·25	4,570	4,460	9·00	7,350	6,850
4·50	4,720	4,610	9·25	7,520	6,990
4·75	4,880	4,740	9·50	7,690	7,140
5·00	5,030	4,850	9·75	7,810	7,250
5·25	5,150	5,000	10·00	8,000	7,350
5·50	5,290	5,130	10·25	8,200	7,460
5·75	5,460	5,260	10·50	8,330	7,630
6·00	5,620	5,380	10·75	8,470	7,750
6·25	5,750	5,490	11·00	8,700	7,870
6·50	5,880	5,620	11·25	8,850	8,000
6·75	6,020	5,750	11·50	9,090	8,130
7·00	6,170	5,850	11·75	9,260	8,260
7·25	6,330	5,990	12·00	9,430	8,400
7·50	6,450	6,100	..	..	..

TABLE VII.—HP. REQUIRED TO BE PROVIDED FOR EACH CUBIC FOOT OF AIR USED PER MINUTE.

Manometer Indication in lbs. per Square Inch.	Pressure. Volume of Compressed Air assumed to enter Tube during transit.	Pressure. HP. required per Cubic Foot of Compressed Air.	Vacuum. Volume of Rarefied Air assumed to leave the Tube during the transit.	Vacuum. HP. required per Cubic Foot of Rarefied Air.
lbs.	(Volume of Tube = 100.)		(Volume of Tube = 100.)	
3	94·0	0·014	108·8	0·012
4	92·2	0·019	113·1	0·016
5	90·7	0·024	117·6	0·018
6	89·4	0·029	123·3	0·022
7	88·3	0·035	130·4	0·024
8	87·1	0·040	139·0	0·025
9	86·1	0·046	150·7	0·026
10	85·1	0·052	166·4	0·028
11	84·2	0·058	189·7	0·028
12	83·5	0·064	227·5	0·026

APPENDIX II.

PRACTICAL RULES AND EXAMPLES OF THE USE OF THE FOREGOING TABLES.

I. Velocity.

To find the velocity (s) *of a carrier in a tube whose length* (l) *and diameter* (d) *are given in feet, and the effective pressure or vacuum in lbs.*

$$\text{For pressure-working, } s = n\sqrt{\frac{d}{l}} \text{ feet per sec.}$$

$$\text{In vacuum-working, } s = n^1\sqrt{\frac{d}{l}} \text{ feet per sec.}$$

The values of n are found in Table V.; those of n^1 in Table VI.

II. Equal Velocities.

To maintain the same velocity in different lengths (l and l_1) *of the same size tubing*, the pressure must be varied so that

$$\sqrt{l} : \sqrt{l_1} :: n : n_1,$$

n and n_1 being the numbers proportional to the velocity given in Tables V. and VI.

Example.—A tube is 659 yards long, and a second tube 980 yards, both 2¼ inches in diameter. When worked with 6 lbs. pressure, the speed of the carrier in the first tube is 50 feet per second.

Required, the pressure or vacuum necessary to maintain the same speed in the second tube.

By Table V. the proportional velocity may be found of 6 lbs. intermittent pressure to be 2·433;

Therefore $$\sqrt{659} : \sqrt{980} :: 4980 : 6070,$$

which is the proportional number of 9½ lbs. intermittent pressure, and of 6·9 lbs. continuous vacuum.

To maintain the velocity the same in equal lengths of tubes of the different diameters, the pressures must be varied so that

$$\sqrt{d_1} : \sqrt{d} :: n : n_1,$$

n and n_1 being the numbers (*vide* Tables V. and VI.) which are proportional to the speeds.

Example.—A given tube is 1½ inch diameter ($= d$), and that to a second station is 2¼ inches diameter ($= d_1$), both being 590 yards long. When worked with 3·75 lbs. continuous vacuum, the speed of a carrier in the latter is 44 feet per second.

Required, the pressure and vacuum necessary to maintain the same speed in the former tube.

By Table VI. the proportional numbers of 3·75 lbs. continuous vacuum are found to be 4270;

Therefore $$\sqrt{1\tfrac{1}{2}} : \sqrt{2\tfrac{1}{4}} :: 4270 : 5230,$$

which is the proportional number for 6·7 lbs. intermittent pressure, and for 5·4 lbs. continuous vacuum.

To maintain the velocity the same when the lengths and diameters are both unequal, it is necessary that

$$\sqrt{\frac{l}{d}} : \sqrt{\frac{l_1}{d_1}} :: n : n_1,$$

n and n_1 being the proportional numbers in Tables V. and VI. as before.

Example.—A given tube is 669 feet long and 1½ inch diameter; and with 5½ lbs. pressure a carrier passes with a speed of 70 feet per second. What pressure and vacuum will drive a carrier at the same speed through a tube 1,698 feet long and 2¼ inches (= 0·1875 foot) diameter?

The proportional number of 5½ lbs. intermittent pressure is by Table V. = 4760;

Therefore $$\sqrt{\frac{669}{\cdot 125}} : \sqrt{\frac{1698}{\cdot 1875}} :: 4760 : 6060,$$

which is the number proportional to 10¼ lbs. continuous pressure, and 6·8 lbs. continuous vacuum.

When, with a given tube, and a pressure p, *a velocity* (s) *is obtained, if any other velocity* (s_1) *be desired*, it is necessary that

$$s : s_1 :: n : n_1,$$

n being the proportional number for p, and n_1 that for p_1 in Tables V. and VI.

Example.—In a given tube a velocity of 30 feet per second is obtained, with an effective pressure of 6 lbs.

Required, the pressure which will give a velocity of 40 feet per second.

In Table V. the proportional number of 6 lbs. intermittent pressure is 4980;

Therefore $$30 : 40 :: 4980 : 6640,$$

which is the proportional number of 11¼ lbs. intermittent pressure and of about 7¼ lbs. vacuum, either of which is the answer.

III. Transit Times.

With equal pressures to maintain the times of transit equal in two tubes of different lengths and diameters, it is necessary that

$$l^3 : l_1^3 :: d : d_1.$$

Example.—With the same pressure, or vacuum, the time of transit of a carrier would be the same in a tube 1,000 yards long and 3 inches diameter as in a tube 793 yards long and 1½ inch diameter.

To maintain the time of transit the same in different lengths (l and l_1) *of the same size tube*, the pressures must be so arranged that

$$\sqrt{l^3} : \sqrt{l_1^3} :: n : n_1,$$

n and n_1 being the proportional velocities in Tables V. and VI.

Example.—A carrier going through 980 yards of 2¼-inch tube with a pressure of 6 lbs. occupied 82 seconds.

What pressure and vacuum are necessary to bring a carrier through 659 yards of 2¼-inch tube in the same time?

The proportional number of 6 lbs. intermittent pressure (Table V.) is 4980;

Therefore $$\sqrt{980^3} : \sqrt{1059^3} :: 4980 : 5570,$$

which is approximately the number proportional to 7·75 lbs. intermittent pressure and 6·5 lbs. continuous vacuum, either of which will fulfil the conditions required.

To maintain the time of transit the same in equal lengths of tubes of different diameters (d and d_1), the pressures must be arranged so that

$$\sqrt{d_1} : \sqrt{d} :: n : n_1,$$

n and n_1 being as before.

Example.—Through a 2¼-inch tube, with 3¾ lbs. continuous vacuum, a carrier passed in 40 seconds.

What intermittent pressure and what continuous vacuum would drive it through the same length of 1½-inch tube?

Table VI. gives the proportional number of 3¾ lbs. continuous vacuum = 4270;

Therefore $$\sqrt{1\tfrac{1}{2}} : \sqrt{2\tfrac{1}{4}} :: 4270 : 5230,$$

which is the proportional number of 6¾ lbs. pressure and also of 5½ lbs. vacuum.

To maintain the times of transit the same when lengths (l and l_1) *and diameters* (d and d_1) *are both unequal*, it is necessary that

$$\sqrt{\frac{l^3}{d}} : \sqrt{\frac{l_1^{\,3}}{d_1}} :: n : n_1,$$

n and n_1 being the proportional numbers of Tables V. and VI.

Example.—If the carrier through 1,698 feet of 2¼-inch tube, with an intermittent pressure of 9½ lbs., took 25 seconds in transit, what pressure must be used in order that a carrier may go in the same time through a tube 1,800 feet long and 3 inches diameter?

The proportional number, n, of 9½ lbs. pressure (Table V.) is 6170;

Therefore $$\sqrt{\frac{1698^3}{\cdot 1875}} : \sqrt{\frac{1800^3}{\cdot 25}} :: 6170 : 5480,$$

which is the proportional number approximately of 8·45 lbs. pressure.

In a given tube, when, with a pressure p, *a time of transit* (t) *is obtained, if any other time of transit* (t_1) *be desired* it is necessary that

$$\frac{1}{t} : \frac{1}{t_1} :: n : n_1,$$

n and n_1 being the proportional numbers of the pressures in Tables V. and VI.

Example.—With a pressure of 10 lbs. a carrier went through a tube 314 yards long in 15 seconds. It is desired to drive it through the same tube in 20 seconds.

Required, the pressure necessary to do this.

The proportional number of 10 lbs. intermittent pressure is 6330;

Therefore $$\frac{1}{15} : \frac{1}{20} :: 6330 : 4750,$$

which is the proportional number of 5·5 lbs. pressure.

The time of transit of a carrier in a tube by $\left\{\begin{matrix}\text{pressure}\\ \text{vacuum}\end{matrix}\right\}$ *being given, to find the* $\left\{\begin{matrix}\text{vacuum}\\ \text{pressure}\end{matrix}\right\}$ *required to effect the transit in the same time.*

Use Tables V. and VI. Having found the proportional number for the given pressure, or vacuum, find the vacuum or pressure in the other table corresponding to the same proportional number.

Example.—With 6 lbs. intermittent pressure a carrier traverses a given tube in 34 seconds. What continuous vacuum would effect the same?

In Table V. the proportional number is found of 6 lbs. pressure = 4980; and in Table VI., opposite 4880, we find 4·75 lbs. vacuum.

To find (1) *the volume of air per minute, and* (2) *the engine power required to work a pneumatic tube when* (1) *the length,* (2) *diameter,* (3) *time of transit, are given.*

1. Divide the given time of transit by the constant (K) given for length and diameter in Table III.
2. Refer to Table IV. and find to what pressure or vacuum the quotient corresponds.
3. Multiply the length by 60 and divide by the time in seconds. This gives the speed (*s*) in feet per minute.
4. Multiply this speed (*s*) by the transverse sectional area of the tube in square feet; that is to say, by ·0123 for 1½, by ·0276 for 2¼, and by ·049 for 3-inch tube. This gives the mean volume of air per minute in cubic feet.
5. Multiply this mean volume by the sum of the two end (actual) pressures divided by twice the actual pressure of the pumping end. This gives the actual volume of compressed or rarefied air to be provided.
6. Refer to Table VII. and multiply the HP. per cubic foot (given in the column opposite the requisite pressure or vacuum) with the volume found by 5. This will be the engine power required.

Example.—What volume of air per minute and engine power will be required to work a tube 3,000 feet long, 2¼-inch diameter, in which not more than 61 seconds must be occupied by a carrier in transit?

1. Table III. gives for 3,000 feet, 2¼-inch tube, K = 37·9

$$\frac{61}{37\cdot9} = 1\cdot61 \text{ nearly.}$$

2. In Table IV. it is shown that 1·61 corresponds with 9·6 lbs. intermittent pressure, and with 7 lbs. continuous vacuum.

3. $\frac{3000 \times 60}{61} = 2951$ feet per minute.

4. The transverse sectional area of a 2·25-inch tube is ·0276 sq. feet, and ·0276 × 2951 = 81·4 cubic feet per minute.

5. The actual pressure is: Pressure 14·75 + 9 = 23·75 lbs.
Vacuum 14·75 − 6¼ = 8·5 lbs.

Therefore $81\cdot4 \times \frac{23\cdot75 + 14\cdot75}{2 \times 23\cdot75} = 66$ cubic feet compressed air,

and $81\cdot4 \times \frac{8\cdot5 + 14\cdot75}{2 \times 8\cdot5} = 116$ cubic feet rarefied air,

to be provided per minute.

6. In Table VII. it will be found that for 9·6 lbs. effective pressure, 0·050 HP. corresponds; and that opposite 7 lbs. vacuum stands ·024 HP.

·050 × 66 = 3·4 HP. requisite for pressure.
·024 × 116 = 2·8 HP. requisite for vacuum.

GENERAL USEFUL APPROXIMATE PROPORTIONS FOR PRESSURE-WORKING.

1. With equal pressures the same velocity is maintained in two tubes of different diameters (d and d_1) and different lengths (l and l_1) when

$$d : d_1 :: l : l_1.$$

2. The same velocity is maintained approximately in different lengths (l and l_1) of the same sized tubing when

$$l : l_1 :: h : h_1,$$

h and h_1 being manometer indications.

3. The velocity is maintained approximately the same in two tubes whose lengths (l and l_1) and diameters (d and d_1) are both unequal when

$$\frac{l}{d} : \frac{l_1}{d_1} :: h : h_1.$$

4. If the velocity (s) with a pressure (h) is wished to be increased to (s_1) the pressure must be increased to (h_1) so that

$$s^2 : s^2_1 :: h : h_1.$$

5. The time in seconds which a carrier takes to go through a tube is

$$t = \cdot 000482 \frac{1}{\sqrt{h}} \sqrt{\frac{l^3}{d}}.$$

h being in lbs. per square inch.

6. The time of transit is maintained in different lengths (l and l_1) of the same sized tubing if

$$l^3 : l^3_1 :: h : h_1,$$

h and h_1 being manometer indications.

7. The time of transit is the same in equal lengths of tubes of different diameters (d and d_1) if

$$d : d_1 :: h_1 : h,$$

h and h_1 being manometer indications.

8. The time of transit is the same in two tubes of different diameters (d and d_1) and lengths (l and l_1) if

$$\frac{l^3}{d} : \frac{l_1^3}{d_1} :: h : h_1,$$

h and h_1 being manometer indications.

9. If a transit time (t) is found with a pressure (h), any other time (t_1) will be found with (h_1), so that

$$t_1^2 : t^2 :: h : h_1.$$

10. If the volume of air per minute required for a tube at a pressure (h) is known, the volume (v_1) required for any other pressure (h_1) is found by the proportion

$$v : v_1 :: \sqrt{h} : \sqrt{h_1}.$$

11. If a given volume of air at a pressure (h) requires an engine performance HP., the same volume at the pressure (h_1) will require a performance HP_1., and

$$h : h_1 :: \text{HP.} : \text{HP}_1.$$

12. The HP. required whilst driving a carrier through a tube is directly proportional to the cube of the velocity

$$\text{HP.} : \text{HP}_1. :: v^3 : v_1^3.$$

November 23, 1875.

THOS. E. HARRISON, President,
in the Chair.

No. 1,445.—"Experiments on the Movement of Air in Pneumatic Tubes." By M. CHARLES BONTEMPS. Translated by JAMES DREDGE.[1]

(Plate 6.)

I.

THE establishment of pneumatic lines, for the distribution of telegraphic despatches in the interior of Paris, has given an opportunity for investigating the movement of the air in the tubes. The following communication records the first results of this investigation, commenced in 1871. The despatches to be forwarded are inclosed in cylindrical carriers forced through the tubes by the pressure of air. This air is compressed by a pump driven by a steam-engine. It was expedient at first to ascertain the law of distances and of times, and to this end a system of registration was established. Electric indicators were placed in connection with the tubes at known distances, the passage of the carrier over each of the points occupied by the indicators being recorded by a chronograph at the end of the line.

A brief description of the arrangement is necessary. The indicator consists of a prismatic box, T, Figs. 1 and 2, attached to the tube in such a way that the knob *a* projects slightly into the tube. Within the box are two cams, *b* and *l*, free to move upon their axes, and two springs, *r* and *s*. The cam *l* is formed as shown in the diagram, and is insulated from the box: the wire from *l* is in connection with a chronograph and battery. When the carrier, in traversing the tube, comes in contact with the knob *a*, the cam *b* is displaced, the spring *s* presses upon the cam *l*, the circuit is closed, and a mark is produced upon the chronograph. This instrument is shown in Figs. 3, 4, and 5. It consists of a train of clockwork, A, giving motion to a cylinder, C, round which has been wrapped a sheet of smoked paper. Parallel to the axis of the cylinder there moves, driven by a weight, *p*, the cord of which is wound upon an axis, a carriage bearing two electro-magnets, *a* and *b*. The electro-magnet *a* is in connection with the indicators upon the tube; the electro-magnet *b*

[1] The discussion upon this Paper was taken in conjunction with the preceding one, and occupied portions of three evenings.

is connected with an electric clock beating seconds. E
armatures is terminated by a fine point, which reprodu
cylinder the oscillations of the palette.

The mode in which the experimental apparatus was a
shown in Fig. 6. The markers T, T^i, T^{ii}, T^{iii}, T^{iv} mark ou
S is the electric clock which beats seconds for the chrono
The carrier is driven through the tube; each passag
points T, T^i, T^{ii}, T^{iii}, T^{iv} is registered by a deflection in
line, produced by the point on the electro-magnet *a*,
blackened paper rolled around the cylinder. The corr
line traced by the point *b* is broken at equal intervals
tions, each representing the duration of one second. A
the observation has been taken, the sheet of blackene
removed by running the point of a penknife along a
line. The paper is then plunged in a bath of gum di
alcohol, which fixes the lampblack. Dried and stret
sheet presents the form of a rectangle, Fig. 7, on which
series of straight lines, produced alternately by the actio
clock and by that of the indicator. The moment of despatc
carrier is also noted electrically, by means of a commuta
to the cock by which communication is opened from the res
the tube. On the lines corresponding to the electro-mag
Fig. 7, will be recognised, commencing with the momen
parture O, the periods t, t^i, t^{ii}, t^{iii}, t^{iv} corresponding to t
when the carrier passes the studs T, T^i, T^{ii}, T^{iii}, T^{iv}, Fig. 6

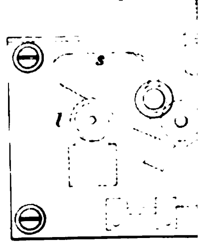
Collecting the figures marked on the diagrams, Figs.
which refer to one experiment, the following table is
at:—

			Distances run.						Time in
O	to	T	= 65·70 mètres	=	215 ft.	6⅝ in.	..	..	2
T	„	T^i	= 440·20 „	=	1,444 „	2$\frac{11}{16}$ „	..	..	27
T^i	„	T^{ii}	= 295·20 „	=	968 „	6$\frac{1}{16}$ „	..	..	27
T^{ii}	„	T^{iii}	= 848·80 „	=	2,784 „	9¼ „	..	..	79
T^{iii}	„	T^{iv}	= 394·20 „	=	1,293 „	3$\frac{11}{16}$ „	..	..	31

It will be convenient now to enter into some details
experiment itself, in order to classify the general resu
tained. And first, as to the line of tubes. This line, indica
Fig. 8, has a total length of 2,044·10 mètres (6,704 feet 8 in
it is composed of two parallel tubes, but experiments we
carried out with one of these.

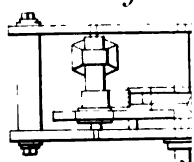
The tubes are of wrought iron, of the common type em
in the pneumatic system of Paris; their inside diameter is
mètre (2·52 inches), and they are connected in lengths of 5 m
(16 feet 4¾ inches) by bolts, rubber rings being introduc
make the joints tight. This system is perfectly efficient

Fig: 1.



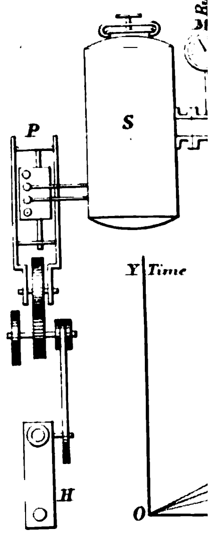
ELEVATION.

Fig: 2.



PLAN.

ELECTRIC INDI



CH. BONTEMPS, DE

Rue de Grenelle.

leaves the interior of the tube undisturbed. The line connects the central station of the Rue de Grenelle, St. Germain, with the station of the Place du Théâtre Français. There are few variations in the level throughout, the most important being shown on the diagram; the curves, however, are numerous, though for the most part of considerable radius. Under these conditions the transit of the carriers is but little impeded, and the general results may be considered, in this preliminary investigation, as referring to a straight horizontal line. The tube is laid partly in the ground, partly in the subways below the street. This latter position was very convenient for connecting the markers, which could there be easily attached and inspected. Beside the tube are disposed the wires which couple each marker to the Central Station, where the registering apparatus is placed. The diagram shows the lengths of the tube laid in the ground, as well as those in the subway, and indicates also the streets traversed.

On leaving the bureau containing the transmitting apparatus, on the ground-floor in the telegraph office of the Rue de Grenelle, the tube crosses (at a distance of 65 mètres) a cellar, where the first marker was placed. From this point the tube lies in the ground, under the Rue Casimir Périer and Rue St. Dominique, as far as the sewer in the Rue Solferino, which it follows till the Pont Solferino is reached. In this sewer, near the points of entry and of exit, were placed the second and third markers. After the Seine has been traversed, under the side-walk of the bridge, the line enters the garden of the Tuileries, which it quits to enter the sewer of the Rue de Rivoli, where the fourth marker was placed. Lastly, it goes by the Rue de Rohan to the station of the Place du Théâtre Français, and a fifth marker was attached, before the tube enters the receiving apparatus.

Fig. 6 will represent in the experiment taken as a type, the position of the five markers, and also of the electric commutator which indicates on the cylinder of the chronograph the commencement of movement.

In order to make the condition clearer, the names of each of the points, taken from their position on the line, are given below with distinctive letters:—

	O.	T.	T^i.	T^ii.	T^iii.	T^iv.
Names of stations . .	Station Rue de Grenelle.	Cellar Rue de Grenelle.	Solferino No. 1.	Solferino No. 2.	Rivoli.	Théâtre Français.
Distances from commencement . .	0	mètres. 65·70= ft. 215 in. $6\frac{5}{8}$	mètres. 505·90= ft. 1,659 in. 8	mètres. 801·10= ft. 2,628 in. $3\frac{5}{16}$	mètres. 1,649·90= ft. 5,413 in. $1\frac{1}{4}$	mètres. 2,044·10= ft. 6,704 in. $8\frac{3}{16}$
Time of transit	0	2·3 sec.	30 sec.	57 sec.	136 sec.	167 sec.

Series A.—The arrangement of the experiment, Fig. 9, is explained by the note attached to the diagram, in which the different parts are indicated as follows: M is the pressure gauge, T the tube, R the communicating cock, *f* the door in the tube through which the carrier is introduced, *g* is the carrier, H the engine, P the air-compressing pump, and S the reservoir.

One of the first results gathered from these experiments was shown by the indications of pressure gauge M placed on the pipe admitting the compressed air from the reservoir to the tube. At the moment when transmission is commenced by opening the cock R, the gauge index falls—then rises, till it reaches a fixed point always less than its initial, and this position it maintains during the whole of the transit while the air-compressing motor is in operation. From this fact is deduced the idea of a permanent condition succeeding a variable condition. The registrations of the chronograph have fully confirmed this point.

Fig. 7 shows a mean of more than thirty experiments, made with a piston weighing 600 grammes (19·2 ounces), under identical conditions of working in each case (November 1872).

The following table shows the distances traversed, the periods of transit, and the mean speeds of each portion of the journey, obtained from dividing space by time:—

	Distances between Two Markers	Time between Two Markers.	Mean Speed.
Rue de Grenelle to Cellar	65·70 m. = 215 ft. 6 5/8 in.	2·3 sec. ..	28 m. per sec. = 91 ft. 10 3/8 in. "
Cellar to Solferino No. 1	440·20 m. = 1,444 ft. 2 11/16 in.	27·7 sec. ..	15 m. " = 49 ft. 2 9/16 in. "
Solferino No. 1 to Solferino No. 2	295·20 m. = 968 ft. 6 1/16 in.	27 sec. ..	10·9 m. " = 35 ft. 9 1/8 in. "
Solferino No. 2 to Rivoli	848·80 m. = 2,784 ft. 9 1/4 in.	79 sec. ..	10·7 m. " = 35 ft. 1 1/4 in. "
Rivoli to Théâtre Français	394·20 m. = 1,293 ft. 3 11/16 in.	31 sec. ..	12·7 m. " = 41 ft. 8 7/8 in. "

Analysing this result, it is found that the mean speed of the carrier in the tube, high at the moment of departure, falls rapidly after the first interval, remains constant during the greater part of the transit between Solferino No. 1 and Solferino No. 2, over a distance of 1,144 mètres (3,753 feet 3 inches), and increases slightly in traversing the last section.

The conclusion from these results is, that the slight augmentation of speed towards the end of the journey is due to a secondary

cause which may be neglected for the moment, in order that the full information to be gained from this investigation may be appreciated. The carrier in the tube arrives by degrees at a permanent condition, to a régime, characterised by a uniform rate of travel. Supposing, now, that the flow of air continues after the exit of the piston, nothing will be changed in the condition of the discharge of the air into the interior of the pipe, the gauge M, Fig. 9, will fall slightly and then become steady in its new position, when the pump will always furnish the supply required. This indicates, it may be remarked, that the friction of the carrier only affects the total result to a trifling extent. A similar remark applies to the resistance offered by the studs of the markers in the tubes as the carrier passes over them. The total times remained identical in those experiments when the markers at the ends of the tube were only used.

Series B.—The movement of two pistons having a common direction in the tube may now be investigated.

This experiment is made as follows:—One piston is driven into the line by the air-pressure, and is stopped after it has traversed a certain distance. A second piston is then introduced and is put into motion. This latter tends, in advancing, to push forward the first piston, and it is this common movement that has now to be investigated. The markers already described can be used in these experiments, and the moments of contact of each of the two carriers with the studs may be recorded. The trials upon which the following remarks are based were made in March 1873. The first piston was stopped at the end of six seconds. According to the results of experiments in Series A, recorded before, the carrier lay between the two markers in the cellar, Rue de Grenelle and Solferino No. 1. The second piston was then despatched, and, from the periods of contact of each of the two pistons with the studs, the following table was compiled:—

Position of Indicators.	Passage of 1st Carrier.	Passage of 2nd Carrier.
Departure	—	0
Cellar	—	2·5 sec.
Solferino, No. 1	26·5 sec.	32·0 „
Solferino, No. 2	54·0 „	60·3 „
Rivoli	133·5 „	139·5 „
Théâtre Français	165·5 „	171·25 „

From this table various deductions may be made. And first with regard to the time occupied by each piston in traversing the

interval between two successive markers. These may be tabulated as follows:—

Intervals.	1st Carrier.	2nd Carrier.
Solferino, No. 1 – Solferino, No. 2	27·5 sec.	28·3 sec.
Solferino, No. 2 – Rivoli	79·5 „	79·2 „
Rivoli – Théâtre Français	32 „	32 „

These deductions show that the two pistons require similar periods to traverse similar distances.

The calculation of the time which elapses between the contact of each piston with the same marker also confirms this conclusion.

PERIODS OF CONTACT OF THE TWO PISTONS WITH DIFFERENT MARKERS.

Solferino, No. 1	5·5 sec.
Solferino, No. 2	6·3 „
Rivoli	6·0 „
Théâtre Français	5·75 „

Lastly for one of the pistons—the first, for example—the mean speed in the various intervals between the markers may be deduced:—

Intervals.	Mean Speed of 1st Piston.
Solferino, No. 1 – Solferino, No. 2	10·7 mètres (35 ft. 1¼ in.) per sec.
Solferino, No. 2 – Rivoli	10·6 „ (34 „ 7 5/16 „) „
Rivoli – Théâtre Français	12·3 „ (40 „ 4¼ „) „

A test of the proposition deduced from Series A may here be found, namely—The speed of the piston becomes uniform in the permanent condition; and, further, the two pistons which have acquired their normal distance apart, preserve it throughout the whole journey. The following results, obtained in a second experiment, may be recorded. It was made with two pistons, under the same conditions of pressure, with this difference, that the first piston was stopped at the end of thirty-nine seconds, that is to say, after passing the marker Solferino No. 1. The second piston was then forwarded, and the following table indicates the contacts of each carrier with the successive markers:—

Markers.	Contacts of the 1st Carrier.	Contacts of the 2nd Carrier.
Departure Station	—	0
Cellar	—	2·75 sec.
Solferino, No. 1	—	32·20 „
Solferino, No. 2	18 sec.	61·0 „
Rivoli	96 „	140·0 „
Théâtre Français	126 „	170·5 „

If, in the simultaneous transmission of the two carriers, the time

occupied by the last one in passing the various marking-studs is observed, the following principle may be elucidated:—

The progress of the piston last introduced into the tube is independent of the initial position of the first. Whence it may be deduced that the air occupying the place of any two given carriers (supposing it reduced to films or discs of infinite thinness) advances in the tube by parallel movements, the effect being the same as if the fluid were incompressible, and characterised by this fact, that the original distance between the carriers is maintained.

The experiments were afterwards continued with three pistons, to which a common movement was imparted. These experiments succeeded perfectly.

The result of the principle, that two pistons which have acquired a normal distance apart preserve the same throughout the whole of the transit, may be further considered. Taking into account the remark made above, that the friction of the piston against the sides of the tube modifies but slightly the conditions of the movement due to the air, the proposition may be generalised, and it may be admitted that the same remark applies to the air between the carriers when the movement in the tube is normal. From this it would follow, that the density of the air is constant from the commencement to the end of the transit, when the régime is established. This deduction clashes with the ordinary view upon the permanent condition of gases. There was perfect uniformity in all the gauges connected with the tube, and each section was traversed in the unit of time by the same weight.

In the case of liquids, it will be admitted that each section is traversed also in the unit of time by the same volume; or, otherwise stated, the density remaining constant, the volume contained between two sections, from the beginning to the end, remains constant. But, in the case of gases, the theory of constant density appears incompatible with the variation of the pressure between the two extremities, and the maintenance of an apparently constant temperature throughout the distance subjected to observation.

It must not be lost sight of, that the two laws of Mariotte and of Gay-Lussac, which regulate the constant value for each gas, in its various conditions, by the formula

$$\frac{v\,p}{\mathrm{T}},$$

in which v represents the volume of the weight unit, p the pressure, and T the absolute temperature,

do not permit v to remain constant when p varies, if T does not vary exactly in the same proportion.

To remove this difficulty and yet to maintain the thesis of constant density in the permanent movement of gases, it may be at once said that moist air—the only gas studied by the investigators—does not conform to the formula $\frac{v\,p}{T} = \text{constant}$; and the objection has not, therefore, the value that might have been supposed. If experiments were made with dry gases, it would, of course, be absolutely necessary to show the variations of temperature accompanying those of pressure. This, however, is anticipating results of experiments which do not absolutely belong to the question, and several other subjects in connection with the pneumatic tube remain to be considered.

Series C.—The experiments recorded under the head of Series A were made with a constant pressure of 50 centimètres (19·685 inches) of mercury in the gauge M, Fig. 9. It is now proposed to compare this group with two others in which the constant pressures were 45 centimètres (17·716 inches), and 38 centimètres (14·96 inches) of mercury respectively.[1]

The periods occupied by the piston to traverse two markers were as follows. It is needless to say that the same distance was travelled in each series of experiments:—

	Pressure 50 cen. (19·685 inches).	Pressure 45 cen. (17·716 inches).	Pressure 38 cen. (14·960 inches).
Station Rue de Grenelle . .	—	—	—
Solferino, No. 2	57 sec.	62½ sec.	73 sec.
Théâtre Français	167 „	178½ „	208 „

These respective periods of contact with each marker, in each series, may be compared as follows:—

Pressure 50 cen. (19·685 inches).	Pressure 45 cen. (17·716 inches).	Pressure 38 cen. (14·960 inches).
$\frac{167}{57} = 2\cdot9$	$\frac{178}{62} = 2\cdot8$	$\frac{208}{73} = 2\cdot9$

[1] The figures given for the values of the pressures are not absolutely exact, on account of the want of accuracy in the gauges employed. The only point it is necessary to show, in the comparison here made, is that the pressures remained absolutely constant during the normal period (*période de régime*). Now it is a fact, independent of the operator, that the uniformity results from the spontaneous equilibrium produced between the work of the machine and that of the air-friction, which characterises the normal period. New experiments with special gauges will be made to investigate the influence of pressure on speed during this period.

The practical identity of these three cases is not accidental, and it indicates a general law. The ratio of the periods of transit over two equal distances chosen arbitrarily on the line, is, in the uniform period state, independent of the pressures. This is an indication of a uniform movement when the representative line of distances and of times is a straight line.

To enlarge a little on this point, compare the two rectangular lines O X and O Y (Fig. 10). The lengths O A, O B, represent the distances between the Central Station and the two markers Solferino No. 2, and Théâtre Français, and the lengths

$$A\,a_1,\ A\,a_2,\ A\,a_3;\ B\,b_1,\ B\,b_2,\ B\,b_3.$$

deduced by experiment, represent the times required in the transit, from the point of departure to the last marker in each of the three series.

Experiment proves the correctness of the proportions

$$\frac{B\,b_1}{A\,a_1} = \frac{B\,b_2}{A\,a_2} = \frac{B\,b_3}{A\,a_3}$$

from which it may be inferred that the points

$$a_1, b_1;\ a_2, b_2;\ a_3, b_3;$$

may be found in couples on a given straight line starting from O. Then from this fact may be deduced precise data upon the travel of the piston in the tube. The total transit, composed of a period of variable speed, and a period of uniform speed, conforms to the law of uniform movement. But from the experiments of Series A it follows, that the transit during the period of permanent speed is also uniform; which shows that the period of varying speed follows the same law. This implies no contradiction. The idea of the variable period does not exclude the idea of uniformity; it is only necessary that the mean velocity of the variable period, for each of the three pressures, be in each case equal to the constant speed of the corresponding permanent period.

Summary.

The experiments of Series A lead the investigator to distinguish in the movement of the air a variable condition, followed quickly by a permanent condition, characterised by a uniform speed.

The experiments of Series B have shown that the movement of volumes of air in the tube is parallel in both of these periods.

The experiments of Series C have shown that these results are independent of pressures, that is to say, that they are general.

Objections will, doubtless, be advanced to these deductions, which are based on a series of limited experiments, whence premature conclusions have been generalised. The Author acknowledges the justice of such objections, and he proposes to make other experiments to confirm the results already obtained. It may be permitted to him, however, to particularise the point of departure. The movement of air, or of a fluid which flows in a tube, under conditions where the supply is absolutely equal to the consumption, differs from the vibratory motion which produces sound. The continuity of the pulsation from the commencement, and the transport of matter which results, give to the moving volume a characteristic motion. In order to conceive and to define this, it is necessary to consider the electric undulation in a wire fed by a battery. It is known that this theory has been formed since the time of Ohm, and that it has for its basis the hypothesis of Fourier—the flow in a unit of time between two sections infinitely approximate is proportional to the differences in tension.

Referring to the conclusion drawn from the experiments of Series C, viz., the mean velocity during the variable state, that is to say, the quotient of the distance traversed during this period, by the time occupied, is equal to the speed of uniform movement (1), the Author may remark that in investigating the analogy between the movement of the air in the pneumatic tubes, and that of electricity passing through a wire, he has arrived at this conclusion: The duration of the variable period is independent of the pressure of air in the reservoir (assumed to be infinite) with which the carrier is driven (2).

Without describing in detail the experiment from which the Author has arrived at this conclusion, he will state that he has traced on the chronograph, with a pressure indicator, curves of pressures and of times, for various values of motive pressures, as represented in Fig. 11.

He has found that the abscissa O A, corresponding to the duration of variable time (joining the curve to the straight line), represented this duration in the three cases. Graphic proof by joining the points a_1, a_2, a_3, wants clearness, but the Author has had recourse to this corollary to the principle: the heights $b\,c_3$, $b\,c_2$, $b\,c_1$, ought to be proportional to the initial pressures in the reservoirs measured by $O\,P_3$, $O\,P_2$, $O\,P_1$; in other words, the lines $P_1\,c_1$, $P_2\,c_2$, $P_3\,c_3$, ought to pass through the same point i.

This graphic result has been obtained on the diagrams, in which the indicator has been placed at three different points of the line; with each of them the verification was obtained.

The Author on this occasion limits himself to a simple result, deduced from the two propositions (1) and (2) mentioned above.

Let L = the total length of the line.

T = the total time of transit.

λ = the distance traversed by the carrier during the period of variable movement.

Then $\frac{L}{T} = \frac{\lambda}{\theta}$ [resulting from (1)]. L is a constant, and θ is also a constant [resulting from (2)]; therefore λ T is a constant. From this it follows: That in the pneumatic tube the product of the distance traversed by the carrier, during the variable period, by the time of transit is a constant.

The communication is accompanied by a series of diagrams, from which Plate 6 has been compiled.

APPENDIX.

THE PNEUMATIC TELEGRAPHS OF PARIS.[1]

I. General Description.

In 1865 the establishment of a system of pneumatic transmission for Paris was decided upon, and in the following year an experimental line was laid between the Place de la Bourse and the Grand Hôtel (Boulevard des Capucines). The production of the compressed air by the water of the town having proved successful, an extension of the line was projected connecting the Bourse with what is now the central station, at 103, Rue de Grenelle, St. Germain, an intermediate station between these points being established in the Rue Boissy d'Anglas. When this was completed, a second line was determined on with stations at the Rue Jean Jacques Rousseau, Hôtel du Louvre (Rue de Rivoli), in the Rue de Rivoli, the Rue des Saints Pères, and terminating in the central station. This work was completed in 1867. The tubes were laid in trenches formed in the streets, and they cross the Seine at the Pont de la Concorde and the Pont des Saints Pères. The arrangements at each station were similar, and the apparatus employed for the compression of the air will be described farther on. In 1868 this system was modified. The station in the Rue de Rivoli was removed and replaced in the Place du Théâtre Français, which was connected direct with the Bourse, the station Rue Jean Jacques Rousseau being taken as one of the central *réseaux*. By this change an hexagonal system was formed to be traversed at fifteen-minute intervals, when worked by the method to be shortly described. In 1868 a branch was laid from the Bourse to the Rue Lafayette, and during the next year a station in the Avenue des Champs Elysées was connected with the one in the Rue Boissy d'Anglas. In 1870 the first of the secondary *réseaux* was completed by the following extensions: from the station Jean Jacques Rousseau to Vieilles Haudriettes, thence to the Place du Château d'Eau, to the Boulevard Saint Denis, and from the Boulevard Saint Denis to the Bourse. In 1871 another secondary *réseau* was laid with stations at the Rue Lafayette, the Boulevard Rochechouart, the Gare du Nord, and the Rue Sainte Cécile.

The principal *réseau* on which are the Rue Grenelle, and the Bourse stations, is the common artery for all these branches, and as extensions are made a direct line between these points will have to be laid as follows: a double line will be formed between the central station and that of the Théâtre Français, and a single line between the latter and the Bourse. The traffic on this line will comprise omnibus trains, as in the actual system on the principal *réseau*, and shuttle trains

[1] Condensed from "Engineering," by James Dredge.

between the central station and the Bourse. The increased facility will involve only a small additional outlay, owing to the combination by which reciprocating trains can be run between the Théâtre Français and the Bourse simultaneously. The pressure of the air upon a piston at the Rue de Grenelle station is transmitted to one at the Théâtre Français, and these two would then traverse the double line in opposite directions, with but small expenditure of power. The transit between the stations, Théâtre Français-Bourse, and Bourse-Théâtre Français, will be made without additional expense, the first by the arrangement of the

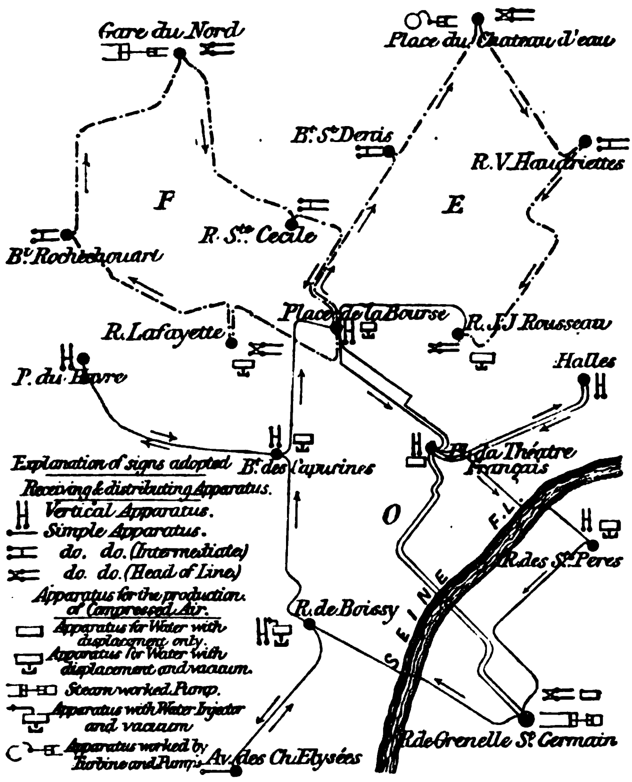


Fig. 4.—General Plan, showing nature of Apparatus at each Station.

reservoirs at the Bourse station, which enables a vacuum to be made in the tube; and the second by making the transits coincide with the Grand Hôtel-Bourse section, and utilising the air escaping from the tube in front of the omnibus train, to drive the train between the Bourse and Théâtre Français stations. The direct line was laid under the above conditions in 1872; the compressing and exhausting apparatus are placed in the Rue de Grenelle. In 1873 the line between the Place du Théâtre Français and the Rue des Halles was made,

consisting of two tubes, serving for exchange of despatches in opposite directions, by pressure exerted at the Théâtre Français station. In 1874 a station in the Place du Havre was connected with the Grand Hôtel by a single tube.

Fig. 4 is a general plan indicating the special appliances at each station, and explaining the mode of working. It will be seen that in the chief *réseau* O, the trains are pushed to Boissy from the central station, to the Grand Hôtel from Boissy, to the Bourse from the Grand Hôtel, to the Théâtre Français from the Bourse, to Saints Pères from the Théâtre Français, and to the central station from Saints Pères. In the secondary *réseau* E, the Bourse station pushes to Saint Denis, the Château d'Eau draws from Saint Denis, and pushes to Jean Jacques Rousseau, and the Bourse draws from the latter. On the secondary *réseau* F, the Lafayette station draws from the Bourse, and pushes to Rochechouart and the Gare du Nord, draws from Rochechouart, and forces to the Bourse with

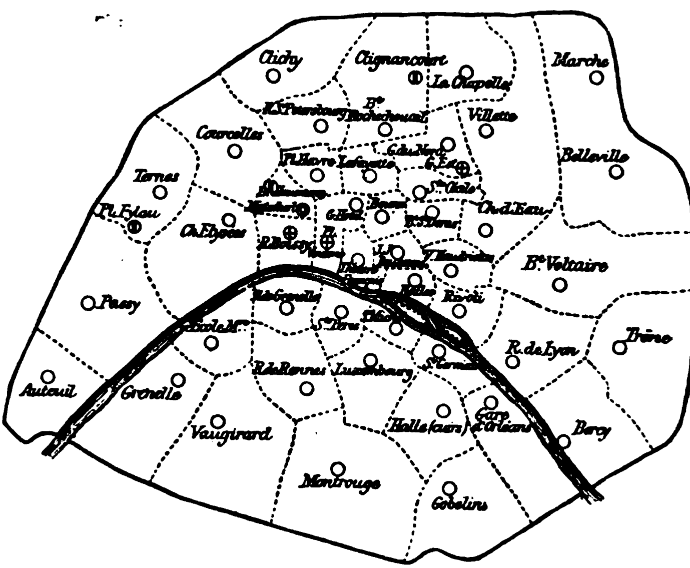


Fig. 5.—Plan showing District Divisions.

the aid of the intermediate station of Sainte Cécile. The three branches (1) Boissy-Champs Elysées, (2) Théâtre Français-Halles, (3) Grand Hôtel-Place du Havre, spring from the principal *réseau* O, and constitute bases for new secondary systems. In Fig. 1 are indicated the different classes of apparatus in use at the various stations to be presently described.

Fig. 5 is a general plan of the whole of the Paris system as it existed in the middle of the year 1875, and it shows the distribution of the forty-six stations now opened. The dotted lines around the stations indicate the district served by each. Fig. 6 shows the present application of the system: seventeen stations only are yet connected, leaving twenty-nine to be dealt with. The following table gives the distribution of the forty-six stations in the chief and secondary *réseaux*.

- Réseau O.
  - Poste Centrale
  - Boissy d'Anglas
  - Grand Hôtel
  - Bourse
  - Théâtre-Français
  - Saints Pères
- Réseau H.
  - Champs-Elysées.
  - Ternes
  - Chaillot
    - Passy.
    - Auteuil.
- Réseau G.
  - Place du Havre.
  - Rue St. Petersbourg
    - Avenue de Clichy.
  - Boulevard Haussmann
    - Boulevard Courcelles.
- Réseau F.
  - Sainte Cécile.
  - Gare du Nord.
  - Boulevard Rochechouart
    - Clignancourt.
    - La Chapelle.
    - La Villette
      - Marché aux Bestiaux.
  - Lafayette.
- Réseau E.
  - J. J. Rousseau.
  - Haudriettes.
  - Château d'Eau
    - Boulevard Voltaire.
    - Place du Trône.
    - Belleville.
  - Boulevard St. Denis.
- Réseau D.
  - Halles.
  - Rue de Rivoli.
  - Rue de Lyon.
- Réseau C.
  - Sénat.
  - Halle aux Cuirs.
  - Boulevard St. Germain
    - Gobelins.
    - Gare d'Orleans.
    - Bercy.
  - Boulevard St. Michel.
- Réseau B.
  - Rue de Rennes.
  - Montrouge.
- Reseau A.
  - École-Militaire
    - Grenelle.
    - Vaugirard.

The number of despatches of all kinds transmitted by the tubes is about 8,300 per day. Of this quantity the more central stations receive the larger proportion. Thus the Bourse station sends out more than 2,500 despatches daily. The mean time which elapses from the handing in of a message to its delivery is, for omnibus train, from forty to forty-five minutes. The work is generally heaviest at mid-day, but some stations reach their maximum earlier or later. The whole of the pneumatic transmission works established in Paris up to the middle of the past year, including besides the stations opened for service, the bases for new lines, and the means of producing power for working a part of those lines, have cost £40,000, and a similar sum will be required to complete the entire scheme.

II. Construction of Lines and Stations.

A. *Tubes.*—The tubes employed in the Paris pneumatic system are of wrought iron, in lengths of from 15 feet to 20 feet, the joints being made by means of flanges and bolts as in Fig. 7. The interior diameter of the tube is 2·559 inches, with a maximum variation to 2·519 inches. The curved portions have radii varying

from 30 feet to 150 feet, and the proportion of curved to straight is about one-seventh. The tubes are laid in the ground at an average depth of 39 inches, and with but slight inclines, except at the stations, where the tube enters at the basement, and is curved upwards, with a radius of from 6 feet to 18 feet, and terminates

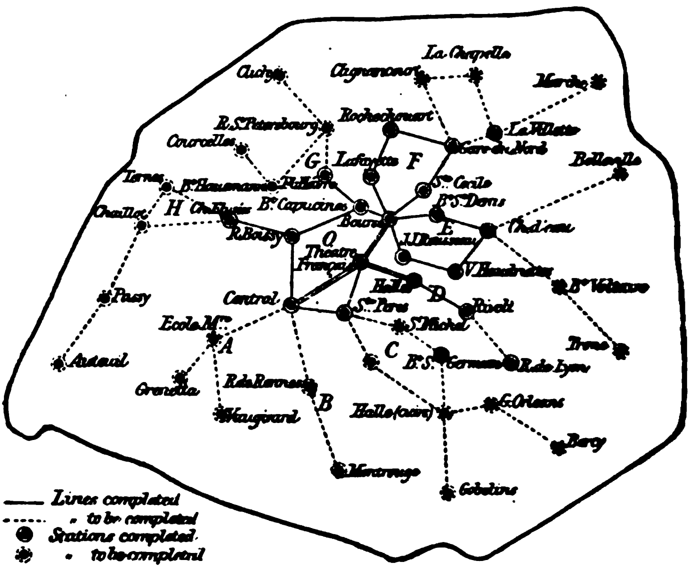


Fig. 6.—Plan showing Lines and Stations completed and projected.

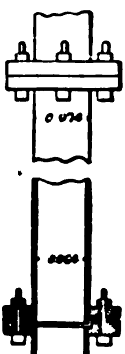


Fig. 7.—Pneumatic Tube and Joint.

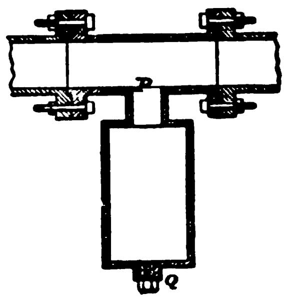


Fig. 8.—Arrangement for draining Tubes.

vertically to adapt itself to the receiving and transmitting apparatus. Where possible the tubes are laid in the subway under the streets, against the sides of which they are supported by brackets 5 feet or 6 feet apart.

Water frequently accumulates in the lowest parts of the tubes, interfering with the traffic. Fig. 8 shows the collector applied to the tube to remove this inconvenience. It consists of a small chamber fastened to the tube in such a way as not to interfere with the passage of the train; the water passes through the

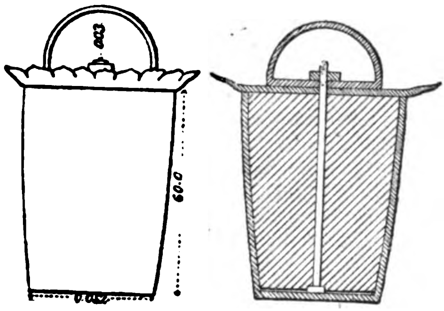


Fig. 9.—Pneumatic Piston.

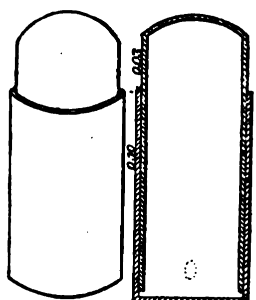


Fig. 10.—Despatch Carrier.

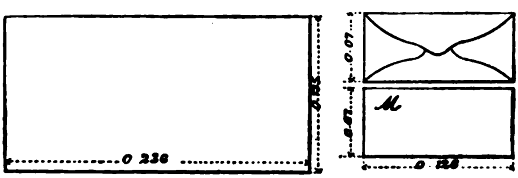


Fig. 11.—Diagram of Despatch.

opening P, and when the chamber is full it can be emptied by removing the plug Q. These sumps are placed in convenient places along the line, where they are easily accessible.

B. *Pistons.*—The pistons are formed of a thin iron plate wrapped around a wooden cone, through which passes a rod with a screw thread cut at one end, which receives a nut to hold the plate that keeps the leather, which is notched

around its edge, in position. The weight of the piston complete is 12·8 ounces. The form and construction are shown in Fig. 9.

C. *The Carriers.*—Fig. 10 shows the arrangement and dimensions of the carriers employed to hold the despatches. They are cylindrical, the outer sheath is made of leather, and the inner of sheet iron. Each carrier can hold from thirty to thirty-five despatches. This form was adopted after many experiments with different forms. It is found that the combination of leather and iron quite protects the contents from dampness and impurities in the tube, and the leather envelope will run for about 1,200 miles before it has to be thrown aside. The iron portion lasts for an indefinite period. The weight of each portion is—for the leather 2·3 ounces; for the iron 6·4 ounces; and the carrier complete, and charged with thirty-five letters, weighs 12·5 ounces.[1]

D. *The Despatches.*—The messages are written on forms the shape and dimensions of which are shown in Fig. 11. Extended the sheet measures 9·30 inches by 5·30 inches, and is folded into an envelope 4·96 inches by 2·75 inches.

The following is a list of dimensions of the tubes, pistons, and carriers employed:—

			Inches.
Tubes	Straight	Standard diameter inside	2·559
		Minimum „ „	2·5197
	Curved	Standard diameter inside	2·559
		Minimum „ „	2·441
	Piston	Diameter of head	2·362
		Length „ „	3·543

		Inches.
Carriers	Outside diameter	2·283
	Length	5·118

E. *Stations.* In Figs. 12, 13, are shown the arrangement of the two storeys of a type station; the reservoir, pumps, turbines, &c., being on the lower floor, and the offices, receiving and transmitting apparatus, above. In some cases, the cellars are made use of to receive the reservoirs, the water being brought in from the street main; or, if necessary, cellars separated from the station building are employed.

III.—Receiving and Transmitting Apparatus.

Two classes of receiving and transmitting apparatus are employed in the stations—vertical and horizontal—the latter being preferable if space permits of its installation. The vertical arrangement is shown in Fig. 14. The tube A is a vertical extension of the pneumatic pipe T. The door P, placed at the bottom of the tube A, serves to introduce or remove the carriers and piston. The two cocks, R and R′, controlled by the handle *m*, are arranged so that when one is shut the other is opened. These establish communication either with the atmosphere or

[1] The two envelopes of each carrier are marked with the same number. It is of great importance that there should be sufficient adhesion between each envelope, so that they should not separate when in the tube, but at the same time it is necessary that they should be easily opened by hand. In working it is customary to change the carriers two or three times a day, as this practice is found to increase their durability. The name of the station or *réseau* is engraved at the bottom of each carrier to facilitate sorting and distribution, and every station is provided with a gauge to check the diameter of the carrier.

with the compressed-air reservoir, according to whether the apparatus is receiving or transmitting despatches. In the former case the cock R is closed, and R′ is opened, and the air in advance of the train escapes, the train rises into the tube A, strikes against the top, and then descends until it is arrested by the fork F. placed in the open door P. The cases are then removed and placed in a basket for distribution. If, on the other hand, a train has to be transmitted, the carriers and piston are placed in the tube through the door P, which is then closed; the cock R is opened and R′ shut, and the compressed air from the reservoir propels the train to its destination.

The horizontal apparatus consists of a conical box mounted on cast-iron brackets. The carriers travel from the tube into the former, and are removed by

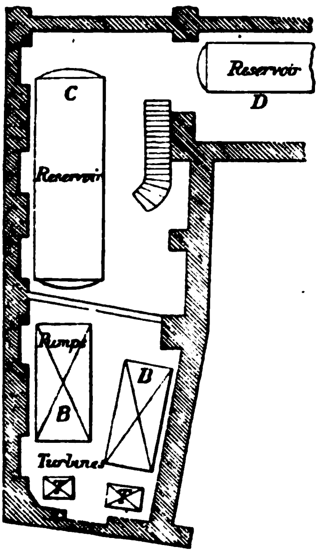


Fig. 12.

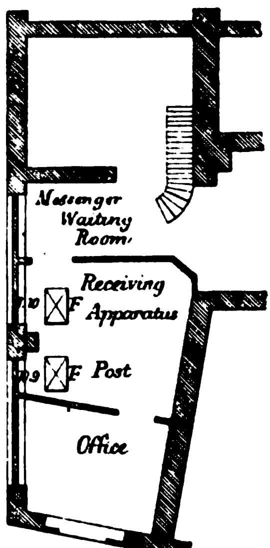


Fig. 13.

Arrangement of Station.

operating a lever, which releases the hinged lid covering the upper part of the box. In transmitting, the carriers are inserted in the tube through the door, which is then closed. A cock at the end of the apparatus places the box and tube in connection with the pressure or vacuum reservoir In the forward part of the apparatus is a valve, operated by a hand-wheel. This valve is used to close the line for different requirements of service. Special receiving and transmitting apparatus are used at intermediate stations where no compressing machinery exists., Thus, suppose there exist three stations, A, B, C, of which B possesses no motive power. It is necessary, therefore, to depend upon the power at one of the terminal stations for the transmission. In working, it is necessary to remove carriers at B, and to replace them by others, and to forward the new train to A or C, according to circumstances. The apparatus employed for this purpose is

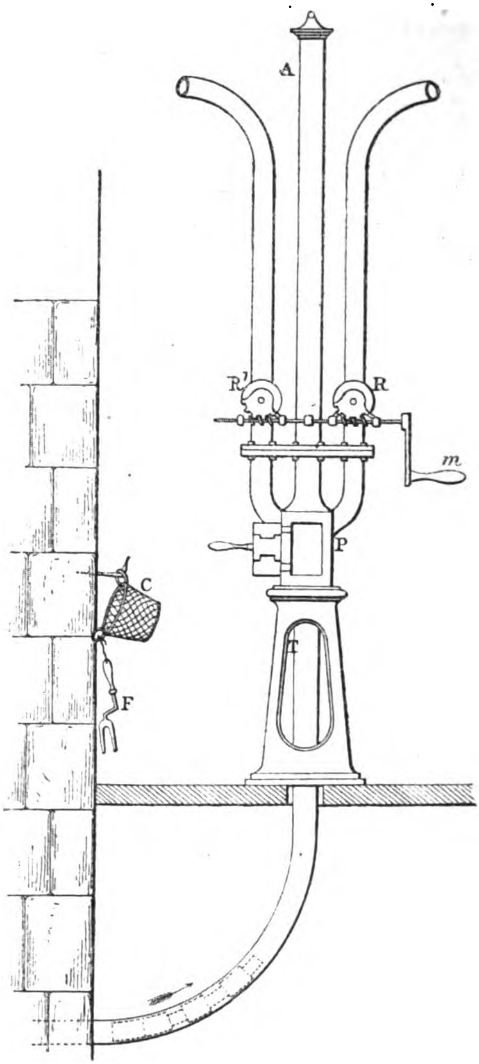


Fig. 14.—Vertical Receiving and Transmitting Apparatus.

shown in Figs. 15, 16. When the train is forwarded to A, the air in front escapes through the opening *c*, the valve *b* being open as well as the valve *a*. The train having entered H, it pushes the spring *r*, and closes the valve *b*, which is held in its new position by the counter-weight *c*. The screw *d* is then moved, so as to close the tube *l*. The cover, A, of the box may then be raised, and the train removed without loss of air-pressure. This being done, the door *f*, Fig. 16, is opened, the carriers and piston of the new train introduced, the compressed air is transferred to the new line by the valve R¹, and the train is then transmitted to Station C.

Fig. 15.

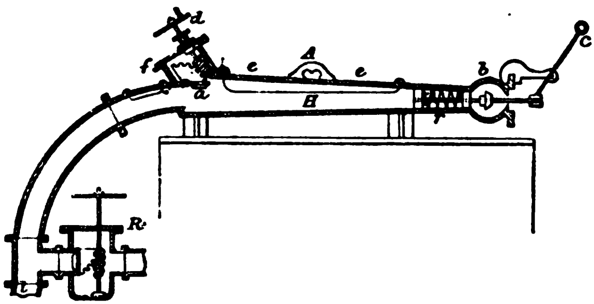
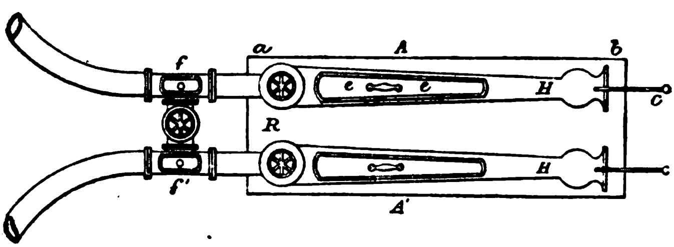


Fig. 16.



Horizontal Distributing Apparatus for Intermediate Stations.

IV.—Air-exhausting and Compressing Apparatus.

Fig. 17 shows one of the means employed for producing a vacuum or compression to work the tubes. In producing compressed air, the water is admitted into the reservoir A, and forces the air contained in it into the receivers B, B, each of about 215 cubic feet capacity. The apparatus is placed on the ground-floor of the station; and between the orifice V¹ of the discharge pipe V V¹ and the point where the water is discharged there is a difference of level ranging between 13 feet and 26 feet. The pipe V¹ ends in a receiver in the sewer. With a difference of level of 16 feet or 17 feet, the power at command in the reservoir will be about half an atmosphere; and when placed in connection with the tube, the train of carriers will be put in motion by the difference of pressure due to the atmosphere on one side, and the partial vacuum on the other. The ordinary dimensions of the receiver A, and the head of water ranging from 13 feet to 26 feet, are sufficient to give a normal speed of from 1,300 feet to 2,000 feet per minute; and this duty

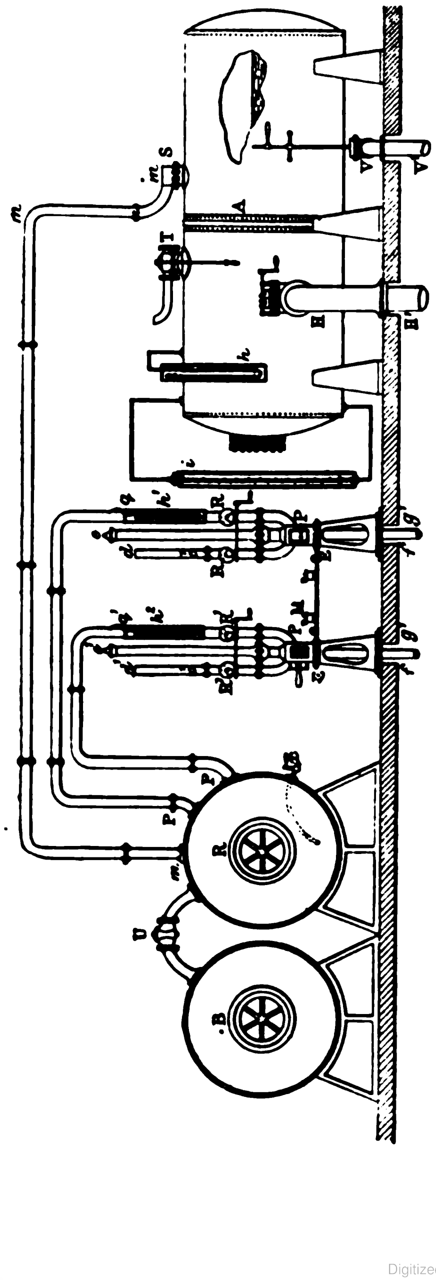


Fig. 17.—Compressing and Exhausting Apparatus.

may be increased by taking away a further quantity of air in the reservoir with the escaping water. The supply pipe for filling the reservoir from the water main is shown at H; B B are the compressed-air chambers, and U is a cock for regulating the communication between them. E E' are the vertical receiving and distributing apparatus; R R are pressure and exhaust valves; M is an electric bell, and S is a check valve; *e e'* are the receiving columns; *f g* are the pneumatic tubes; *m m* is the pipe communicating between the reservoir A and the receiver B; *g p* are the pipes leading from the receivers to the reception apparatus. A modification in this arrangement is shown in Fig. 18, where the exhaust pipes are connected by a pipe *d m*, and extended to the reservoir A. The cocks R and R' are not coupled, but are worked independently, R for transmission under pressure, R' for reception by vacuum. In this arrangement, when the apparatus is employed for reception by compressed air from the adjacent station, the air is

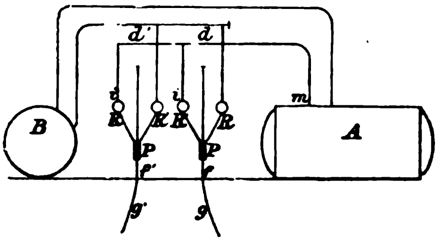


Fig. 18.

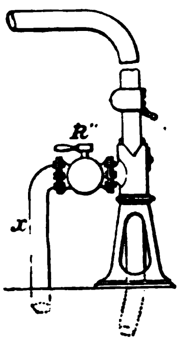


Fig. 19.

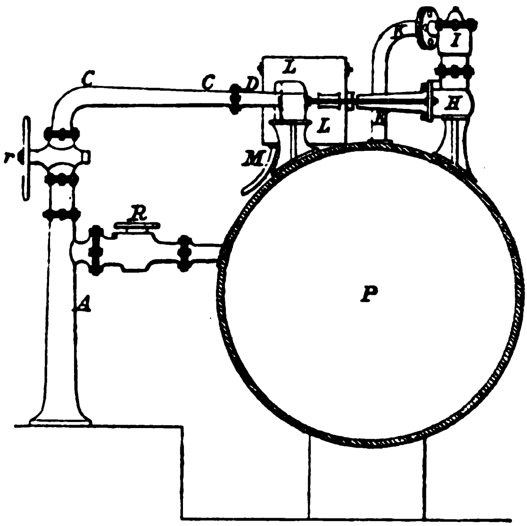
Fig. 20.

exhausted by one of the openings P P. Fig. 19 represents a vertical apparatus, in which, by means of the pipe *x*, closed by the cock R'', the air in advance of the train can be liberated into an underground cellar.

After lengthened experiments, in 1868, considerable economy in working was effected by employing a jet to draw in air for working with compression. Fig. 20 shows the arrangement, in which P is a reservoir of 282·5 cubic feet capacity. The water arriving by the city main passes through the opening O into the apparatus R. This apparatus is provided with a valve, S, for preventing the escape of the compressed air in the reservoir P. Experiments showed that, with a head of water of 28 feet, a quantity of air equal to 0·465 of the volume of water may be drawn into the reservoir; and the final pressure of air obtained was

1·21 inch of mercury. This system possesses great and obvious advantages. By simple displacement, a volume of air at atmospheric pressure, equal to the volume of water removed, is obtained; but by the addition of the induced current arrangement, a volume equal to 1·465 results, representing an economy of about 32 per cent. Figs. 21, 22, show the complete arrangement as designed for a station.

Fig. 21.



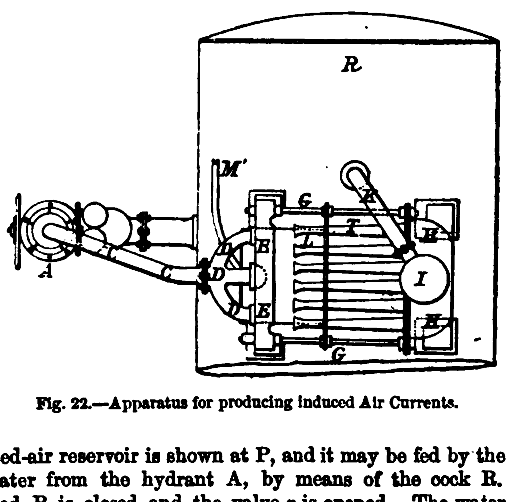


Fig. 22.—Apparatus for producing Induced Air Currents.

The compressed-air reservoir is shown at P, and it may be fed by the direct introduction of water from the hydrant A, by means of the cock R. When the injector is used, R is closed, and the valve *r* is opened. The water then passes by the tube C C D into the box E, and the water is discharged into the tubes T. In Fig. 22, six of these tubes are shown, to represent the proportion necessary

between the amount of discharge and the size of the receiver P. The box E is connected to the box H by the bars G G, the box H receiving the water and the induced air, which pass though the valve box I and pipe K into P. By means of the bar G G the position of the box E, with reference to the mouthpieces T T, may be regulated, so as to obtain the best result.

As well as the modes already indicated, the water has also been utilised by means of turbines, used to drive double-acting pumps for compressing or exhausting the air. With a fall of 39 feet 6 inches, the turbines employed, which are $23\frac{5}{8}$ inches diameter, make 245 revolutions per minute, and discharge 1·72 cubic foot per second when the maximum number of ten openings are supplied. The speed of 245 revolutions is brought down to 22 at the pumps. In the plans of the station (Figs. 12, 13), this arrangement is shown, and may here be again referred to. The basement contains the turbines T, and the pressure and vacuum reservoirs C and D. The water pressure throughout Paris is of course unequal, and at some high stations steam power is resorted to of necessity.

V. Comparative Cost of different Modes of Working.

The comparative cost of working by various methods upon the pneumatic system of Paris has now to be considered. With the arrangements described, a train is despatched with a pressure above the atmosphere of 17·716 inches of mercury, and arrives with a pressure of one-fourth of an atmosphere behind the piston at the end of the line. The journey of 1 kilomètre lasts during one minute and a half (0·417 mile per minute).

The consumption of water amounts to about 236 cubic feet per mile, as will be shown by the following calculation:—

Let V = cubic contents of 1 mile of tube = 188·8 cubic feet.
H = atmospheric pressure = 29·92 inches.
H^1 = departure pressure = 29·92 ins. + 17·71 ins.
h^1 = arrival pressure = 29·92 ins. + 7·48 ins.

$$\text{The water reservoir A} = \frac{h^1}{H} \times \frac{H^1 - H}{H^1 - h^1} V = 407 \cdot 808 \text{ cubic feet.}$$

$$\text{The air reservoir B} = \frac{h^1}{H^1 - h^1} V = 689 \cdot 120 \text{ cubic feet.}$$

At the second operation B being full of air at an effective pressure of one-fourth of an atmosphere, less water will be required to restore the pressure to 17·71 inches. The amount will be

$$A = \frac{h^1}{H} V = \frac{5}{4} V = 236 \text{ cubic feet.}$$

The cost of water being 18·24*d.* per 1,000 cubic feet, the cost of transmitting a train through 1 mile is 18·24 × 0·236 = 4·3*d.*

The accompanying diagram (Fig. 23) represents a principal *réseau* P, and seven secondary *réseaux*, A, B, C, D, E, F, G, serving thirty-three different offices, by means of thirty-nine sections of line. The following traverses have to be made for a complete circuit, as follows:—

$$\begin{array}{l} P - A - B - C - D - E - F - G \\ 6 + 7 + 5 + 6 + 7 + 5 + 5 + 5 = 46 \end{array}$$

Assuming the stations to be 1 mile apart, the cost would be 46 × 4·30 = 197·8*d.* Assuming fourteen hours' daily service, with four trains making the circuit

per hour, the total cost of water will be $197\cdot8d. \times 56 = £46\ 3s.$ per day. To obtain the total cost of distribution, the amortisation of capital, first cost, maintenance, and staff have to be considered. The cost of construction per mile is about £965, and the cost per station about £650.

	£.
Thus the total cost of the thirty-nine sections will be	37,700
" " " thirty-three stations "	19,800
	57,500

Amortisation at 10 per cent. is equal to £5,750. The rental for stations may be taken at £4,620; maintenence and inspection are covered by £38 per mile, or £1,480 in all, and the maintenance of stations will be £1,584. Finally, staff expenses amount to £21,912 The total of all these items, including 10 per cent.

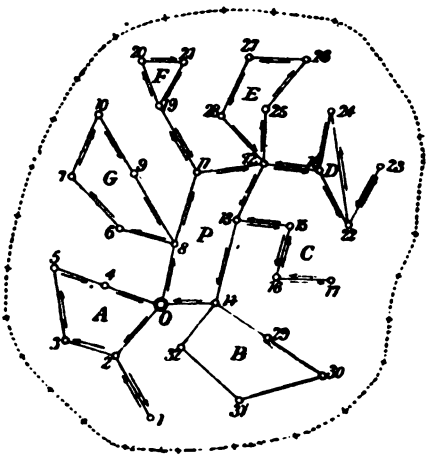


Fig. 23.

for contingencies, amounts to £57,866. The producing power of this *réseau* may be moderately estimated at 15,000 despatches per day, which at 4*d.* per message $= 4 \times 15,000 \times 365 =$ £91,250, leaving a yearly profit of £33,384.

A comparison of the cost of water as above, with that of compressed air and vacuum combined, and again with the displacement combined with induced air currents, gives—

$$1\ldots\ldots 18\cdot24 \times \cdot236 = 4\cdot30d.$$

$$2\ldots\ldots 18\cdot24 \times \frac{\cdot236}{2} = 2\cdot15d.$$

$$3\ldots\ldots 18\cdot24 \times \cdot236\ (1\text{–}32) = 2\cdot927d.$$

From this it will be seen that the first method is much the most costly, and the second and third modes should be employed, to suit local conditions.

Turning now to the cost of working by turbines. The capacity of the air reservoir, and the initial and terminal pressures being as before, to raise 689·12 cubic feet from the pressures equivalent to $29\cdot921 + 7\cdot48$ inches of mercury to

29·921 + 17·716 inches, a capacity of air at atmospheric pressure of 236 feet has to be dealt with. The work to be done to force this into the reservoir at a mean pressure of $\frac{17 \cdot 71 + 7 \cdot 48}{2} = 12 \cdot 6$ inches, is equal to 173,170 foot pounds, and, assuming that a duty of 50 per cent. is obtained from the turbines, the latter will have to develop a total of 346,340 foot pounds, equivalent to a volume of about 154 cubic feet of water under a head of 36 feet. This, the cost of water being as before, gives (4).....18·24 × ·154 = 2·809*d.*, and showing a marked economy over (1) and (3) as above. In making a comparison with (2), and allowing for the extra height, at least 16 feet, through which the water has to fall to produce the vacuum, it will be found that the cost of working by turbines under this increased head is 1·924*d.*

Finally, coming to steam power, and assuming the same foot pounds of work as before, with a length of journey of fifteen minutes, the work performed by the machine is 0·35 HP. Allowing that 70 per cent. of useful work is given out by the pumps, this quantity will be raised to 0·50 HP. per journey, and the cost per journey may be closely approximated at 0·56*d.* But although this means of obtaining power is far cheaper than either of the others, it is inconvenient to make use of it in some of the crowded portions of the city.

VI. Method of Working.

The practical working of the pneumatic system of Paris may now be briefly considered. The carriers forming the train are made up, addressed labels being affixed to the carriers destined for each office, and circulation commences in full activity at 8 A.M. Fig. 23 is a diagram of the system, the arrows indicating the directions of traffic. On the close polygons of the *réseau*, the trains are worked alternately in each direction for three months, to remove any dirt or obstruction which might otherwise accumulate. In winter the trains are more soiled than in summer; the air from the station being heated, deposits the vapour with which it is saturated in the tubes. This inconvenience is partly removed by establishing the air reservoirs in cellars where the temperature is low. A train on being sent from O arrives at station 8, with the forward carrier filled with despatches for 8 and its district, the remaining carriers being for stations 6, 7, 10, 9. The first carrier is removed, and another takes its place, containing the despatches collected at station 8, or 6, 7, 10, 9, which the previous train from *réseau* G has brought here. The newly made-up train is then forwarded on the 8–11 line, and so on round the circle back to O, the operation described being repeated at the stations 11, 12, 13, 14. The train service is controlled by means of the official instructions relating to the actual times of arrival and departure. This time table, and a plan of the *réseau*, to which the station belongs, as shown in Fig. 21, is hung on the wall of the office. Only the times of departure are given, the periods of arrival being deduced. By the formula H + x, where H is the time of departure from the central bureau O, and x a constant time for each station, the moment at which any train, the number of which is known, will pass, is easily ascertained. Exact accord of time between the stations is necessary, and electric communication is established over the whole system. Returning to Fig. 23: at station 11, it will be seen that three *réseaux*, P, E, D, centre at this point, which is consequently one of high importance. Three trains, from 11–12, 23–12, and 18–12, are received and transferred here in the manner already described. To take an example: a despatch left at station 10, at 9h. 35m. A.M., to be delivered in the district served by station 18, is sent on by a train leaving O at

9h. 30m., and quitting station 10 at 9h. 37m. The "omnibus" carrier of *réseau* G leaves it at station 8 at 9h. 41·5m. The message is then transferred to the omnibus carrier of *réseau* P, and reaches station 12 at 9h. 51·5m. There it is placed in the similar carrier of *réseau* D, and reaches station 18 at 9h. 54m. Delivery of the despatch is made fifteen minutes later.

Intimately connected with the working of the tubes is the removal of obstructions which occur from time to time, causing not unfrequently serious inconvenience and delay. The most general cause of obstruction is a stoppage of the train arising from accident to the tube, to the carriers or piston, or to the transmitting apparatus. In such cases the delay is generally very brief, it being for the most part sufficient to reverse the pressure on the train from the next station, and to drive it back to the point it started from. If one or more of the carriers break in the tube, reverse pressure is also generally sufficient to remove the obstacle; but where this fails, the point of obstruction must be ascertained. This is done by carefully observing the variations of air pressure in the reservoir, when placed in connection, first with a line of

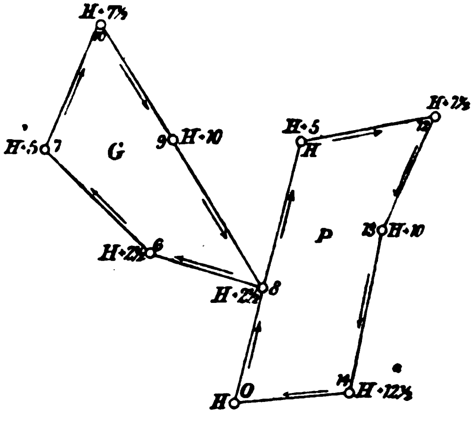


Fig. 24.

known length, and then with the obstructed tube. By this means the position of the obstruction can be ascertained within 100 feet. Or the tube may be probed with a long rod up to a length of 200 feet. A very ingenious apparatus by M. Ch. Bontemps is shown in Figs. 25, 26, and is employed to ascertain the exact position of the obstruction. It acts by the reflection of sound-waves on a rubber diaphragm. A small metal disc is cemented to the rubber, and above this is a pointed screw D. An electric circuit is closed where the points C and D are brought in contact. To locate an obstruction a pistol is fired into the tube as shown, and the resulting wave traversing the tube at the rate of 330 mètres a second strikes the obstruction, and is then reflected against the diaphragm, which in its turn reflects it to the obstacle, whence it returns to the diaphragm. By this means indications are marked on the recording cylinder, and if the interval of time between the first and second indications be recorded, the distance of the obstacle from the membrane is easily ascertained. The chronograph employed is provided with three points: the first of these is placed in a circuit, which is closed by the successive vibrations of the diaphragm; the second corresponds to an electric regulator, marking seconds on the cylinder; and the third subdivides the seconds there marked.

Fig. 27 indicates a record thus made. In this case the obstacle is situated at a distance of 62 mètres, and the vibration marks thirty-three oscillations per second. The interval occupied by two successive marks from the diaphragm on the paper,

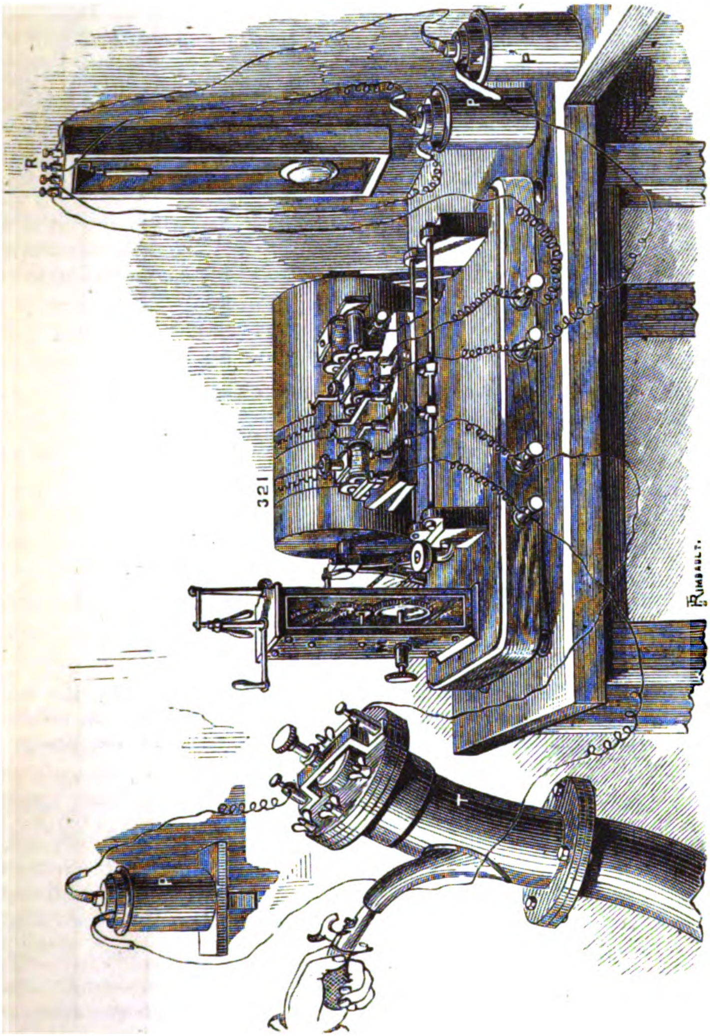


Fig. 25.—Obstruction-recording Apparatus.

corresponds to twelve oscillations, and the distance of the obstruction is then calculated by the following formula:—

$$D = \cdot 5 \times 330 \times \frac{12}{33} = 60 \text{ mètres};$$

so that the distance of the obstacle is recorded within 2 mètres.

Amongst the special causes of accident may be mentioned, the accidental absence of a piston to the train, breaking of the piston, the freezing up of a piston in the tube, and even forgetting the presence of a train, which has caused the

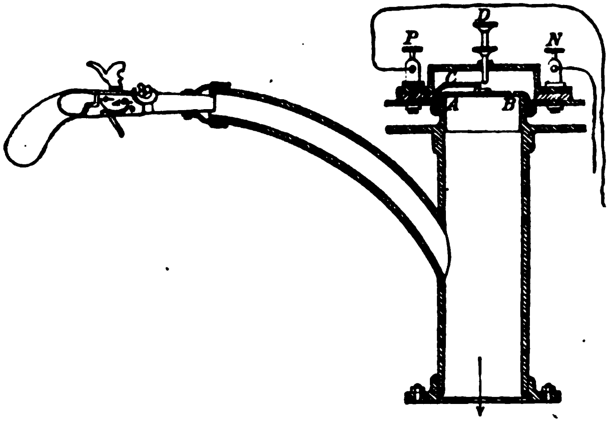


Fig. 26.—Obstruction-recording Apparatus.

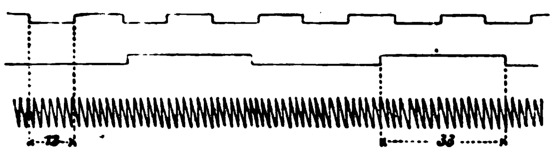


Fig. 27.

entire service to be one train late throughout the day. Finally, the tubes themselves are sometimes broken or disturbed during street repairs, resulting of course in a complete cessation of traffic in the system till the damage is made good.

Dr. Siemens said it was exactly four years since a Paper on the subject of pneumatic propulsion had been brought before the Institution by Mr. Carl Siemens.[1] The object of that Paper was to describe a system of propulsions in tubes which had been matured by his brothers and himself in the course of years, it being a system of continuous flow, or a circuit system. This had been established in Berlin in 1864, in London in 1869–70, and in a modified form in Paris in 1871–72. The scheme had been submitted to the Postmaster-General several years previous to its application in London. The object was to despatch letters throughout the metropolis by a system of circuits, uniting in one or two common centres or pumping stations, whence parcels would be sent out every five minutes to a number of receiving and transmitting stations lying in a circle (similar in appearance to that shown on the diagram representing the Paris system). The current flowed round always in the same direction, conveying with it a succession of carriers passing from any one station to any of the others. The system differed materially from the former method, by which one carrier was sent through a tube in one direction, and went back by vacuum in the opposite direction. Sir Rowland Hill looked favourably upon the scheme, and he was indebted to Mr. E. A. Cowper, M. Inst. C.E., who was at that time frequently consulted on engineering matters by the Post Office, and had previously worked on a similar subject, for his support in recommending its adoption. The present Paper discredited, to some extent, the circuit system, for which it proposed to substitute a "radial system." He was not inclined, however, to accept the verdict of the Authors of the Paper, who, he believed, had not stated all the elements upon which this question should be judged. The circuit system, when first established between Telegraph Street, the General Post Office, Fleet Street, and Charing Cross, was considered a complete success; the postal authorities asked several scientific men and gentlemen connected with the Press to observe its results, and they were extremely pleased with them, but since that time there had been a disposition on the part of their engineers to substitute the radial system. The first objection raised against the circuit system was, that no advantage was derived from it between Telegraph Street and Charing Cross, and that consequently the circuit had been broken up. Fig. 28 represented the circuit as originally established. Pressure

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxiii., p. 1.

was maintained in one reservoir, and vacuum in an the flow of air was always in one direction, carriers be duced at the points indicated on the diagram through a simple construction. It would be observed that was a very oblong one, the intermediate stations on b being locally united for the convenience of the tra alteration since made consisted in the removal of the necting the two branches ending at Charing Cross, so air flowing from the pressure reservoir was discharged atmosphere, and the atmosphere introduced at Char flowed to the vacuum reservoir. It so happened, howeve pressures marked at each station remained at every po circuit the same, Charing Cross being just half-way on ea of the circuit; and, although he quite agreed that it convenient to take away the connecting link, and to w half with the atmosphere inserted in circuit, it ma

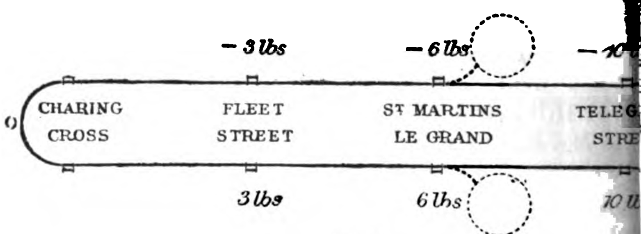
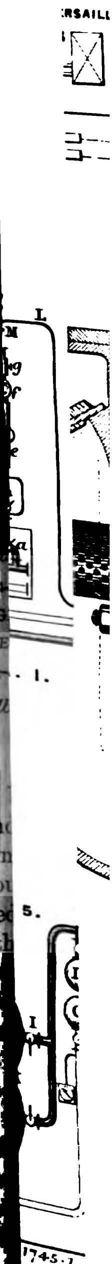
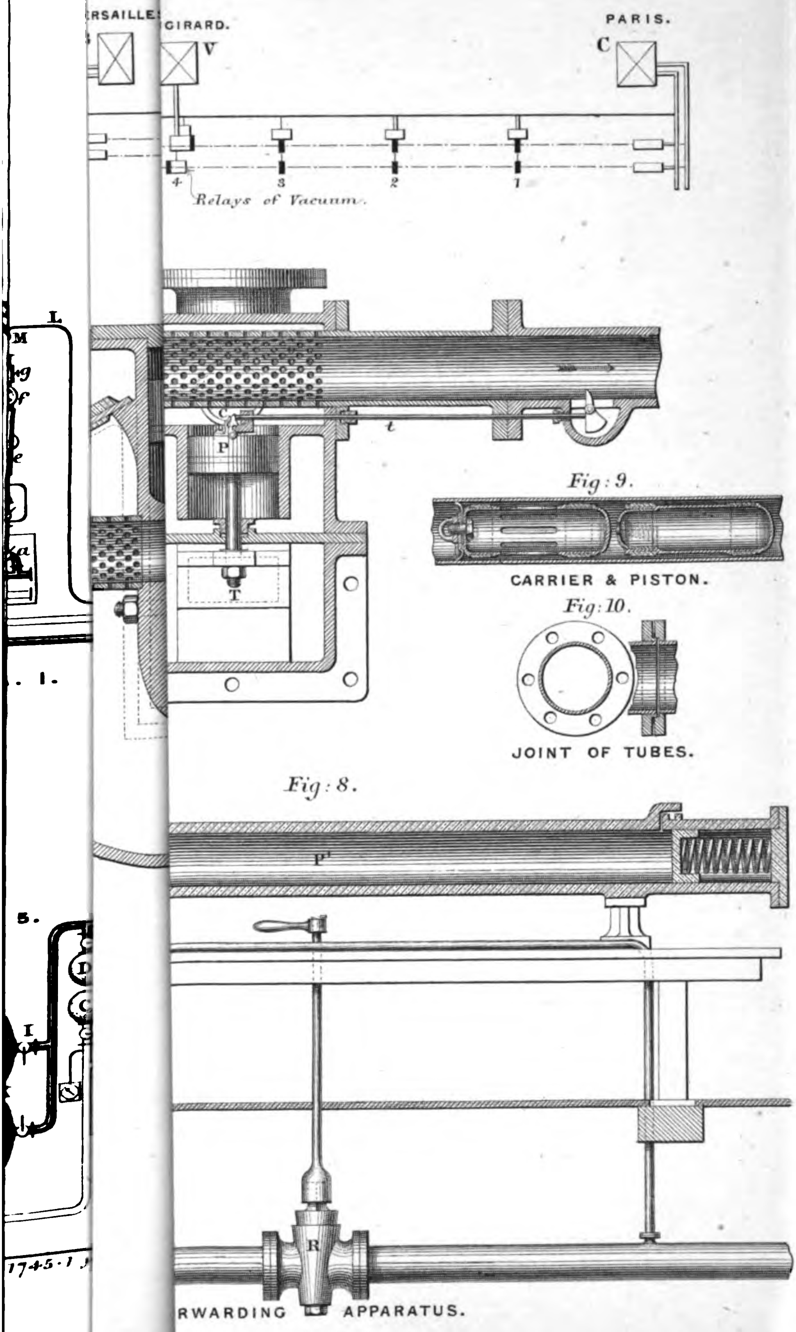


Fig. 28.

ference whatever in the principle of working. It had tended originally to extend the circuit to Westminster; an intention had been carried out, the intermediate instru Charing Cross would have been indispensable. Altho present system was not worked as a circuit, it was worked same continuous method, and it would be observed that th authorities had adopted another similar open circuit bet General Post Office, Cannon Street, and Thames Street, had no doubt worked equally well, and went far to p advantages of the system. Another complaint was, that pipes employed by him (Dr. Siemens) in laying down the Cross circuit were apt to rust in consequence of the use of water in the air-pump which had since been discontinued also stated that injecting water into the air-pump was acc by a waste of power. He entirely dissented from the la position. He had prepared a diagram (Fig. 29) showing of compression: if a piston travelled in the cylinder, the





THOS KELL, LITH. 40 KING ST COVENT GARDEN

would rise, in the manner indicated by the dynamical curve, which compression was accompanied by a rise of temperature from 60° to 170° Fahr., in bringing up the pressure to double that of the atmosphere. By injecting cold water, not only was the cylinder lubricated as stated in the Paper, but the heat was absorbed by the water, the result being that the increase of pressure would not take place in the ratio indicated by the dynamical line, but in that indicated by the other line, which represented the ratio of isothermal compression. Injecting water therefore was not a source of loss of power, but of gain of power. Probably the quantity of water injected had been too small, and in that case no doubt vapour would be carried over into the reservoir. The postal

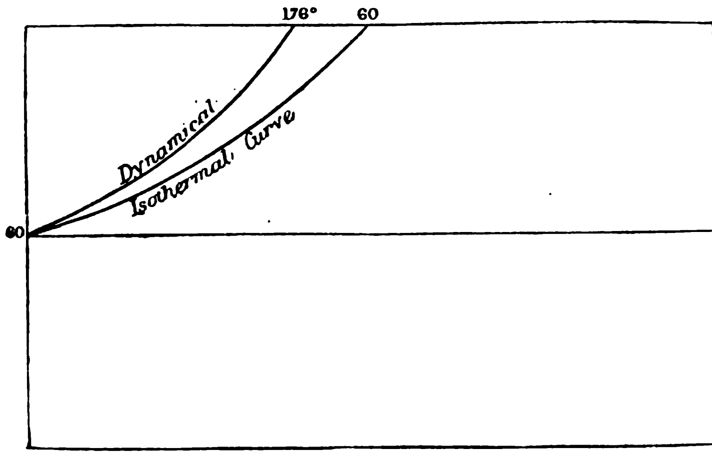


Fig. 29.

authorities had done away with the reservoir altogether, which, he thought, was a mistake, because it was necessary to allow the water to settle and the air to become dry and cooled down to the point at which it was fit to enter the pipes. As regarded rusting, the Authors themselves stated that in Paris, where the air was compressed by water, no inconvenience had been observed on that score, nor had any such effects been experienced in Berlin. If rust had given trouble in the circuit in question, he considered it was entirely due to the mode of working. No doubt a lead pipe was better in some respects for small diameters, but when he designed the circuit, cost was a very important element. He could not afford to have lead pipes inside cast-iron, the cost of which might suit the Post Office, now that the authorities were accustomed to spend their millions somewhat freely;

but at the time to which he alluded they were in the habit of going closely into estimates. No doubt it would have been better to line the inside of the pipes with softer metal, such as tin or lead, in order to obtain a smooth working; and he had proposed to tin the inside of the pipes, but that had to be negatived because it would have been too costly. He should have been glad of the opportunity of comparing the estimates of the two descriptions of pipe, believing, as he did, that one would cost several times as much as the other. Another objection raised in the Paper against the circuit system had been that time was lost at the intermediate stations. He did not, however, see the force of that objection. It was very important that the time of transit from the central station to the extreme end of the system should be as short as possible; but there could be no practical object in shortening the times of transit to the intermediate stations. He would take the case of the second continuous circuit established in London. It had been stated that, in working the circuit from the central station to Cannon Street and Thames Street continuously, the time of transit from the central station to Cannon Street was sixteen seconds more than when the latter was worked as a terminal station, the times of transit being seventy-two and fifty-six seconds respectively. That might be so; but he thought it was rather an advantage than otherwise to retard the flow in so short a tube, and the intermediate station in Cannon Street did not in any way diminish the speed of the flow from the central station to Thames Street. If the two were worked as separate continuous circuits, more than double the air would be consumed as compared with that required to work the three stations on the circuit system. If it were so desirable to diminish the time of transit, it would be much better to increase the diameter of the pipe. In that case there would be an advantage for both stations in point of speed and working capacity, and engine power would at the same time be saved. He thought, therefore, that the objection raised against the intermediate station did not hold good. Another objection was that the iron pipe caused more friction than the lead tubes. No doubt there was a little more friction to the carrier; but, seeing that this constituted a very slight amount in the total friction of the transit of air through the pipe, it was not a serious matter, and could have been avoided if the inside of the iron tube were simply covered with a soft metal.

He had certain objections to make to the theoretical part of the Paper. The Authors started with Zeuner's formulæ, expressing the dynamical effect produced in allowing air to expand from one

pressure to another. They presumed that if the air flowed into a long tube, it expanded in the same manner as if it were allowed to push a working piston forward, which, however, was not the case. If compressed air were allowed to re-expand behind a working piston the temperature would fall in precisely the same ratio in which it would rise in compression, the heat lost being the equivalent of the force communicated to the piston. But was it the same if air expanded into a long pneumatic pipe? Certainly not. There was in that case no working piston with resistance behind it, the carrier piston consisting only of a piece of hose containing some slips of paper, which offered practically no obstacle. All the resistance that had practically to be dealt with in the pneumatic pipe was that of the air itself. Suppose air of 2 atmospheres pressure were admitted at one end of the pipe (which might be 1 mile or 3 miles long), the pressure would taper down to atmospheric pressure at the opposite end. No work was accomplished here, except that exerted upon the air itself in being pushed through the tube, which, therefore, became the recipient, in the shape of heat, of all the force which had been exerted, and the result was that the expansion of the air from 2 atmospheres to atmospheric pressure would not be accompanied by any decrease of temperature. Therefore the dynamical formulæ regarding the force and volume of air expanding behind a working piston did not apply to the case of a pneumatic pipe. Assuming that the pipe itself was a non-conductor of heat, and that the temperature of the air on entering the pipe was the same as the temperature of the pipe itself, he maintained that the air would flow out of the other end of the pipe at exactly the same temperature as that at which it entered. Taking the case of a pipe of conducting material, and assuming that the air entered the pipe at 2 atmospheres pressure and at the temperature of the pipe itself, the temperature at which the air left the pipe must be in excess of that of the compressed air when it entered, inasmuch as the latter had work to perform; it had to push forward the air and overcome its friction against the side of the tube; and, inasmuch as work was performed in the early part of the operation, the temperature of the air would diminish. Heat would be communicated from the tube to the expanded and cooled air; but towards the end of the transit no work, excepting friction, had to be performed, and all the heat that had been picked up by the air in the early part of its transit would appear in the form of additional free heat at the end. After this explanation, he hoped that the Authors would

agree with him that the co-efficients in their formulæ, taken from the dynamical action of expanding air, were not applicable. It might be mentioned that the experiments given at the end of the Paper exactly confirmed his view. In other respects the theoretical considerations involved in this subject had been put forward in a complete and elegant manner, and some of the experimental results were extremely valuable.

Regarding a comparison of the radial with the circuit system, he believed that the advantage was with the latter. The radial system implied a greater number of tubes; and it was, therefore, wasteful in point of cost. It implied, if the radii were worked on the continuous system—which was almost necessary where there was so large a traffic as in London—a greatly increased consumption of compressed or rarefied air, as the case might be. Moreover if there were, say, twenty or thirty stations round the central station it would be practically impossible to lay as many tubes radiating from one centre, each tube consisting of a leaden pipe surrounded by an iron one. The streets would not be sufficient to contain such a number of tubes. Although the radial system might do for collecting messages from offices in the immediate neighbourhood of the central station, he felt sure that whenever the time came for the establishment of the pneumatic despatch system on a large scale, requiring larger diameters and a combination of hundreds of stations (so that a parcel could be sent from any one station to any other), it would be impossible to carry out such an object by the radial system, and a return to the circuit system would be absolutely necessary.

Mr. Preece observed that, as the representative of Mr. Culley, he had to explain, as far as he could, the illustrations of the working of the pneumatic system. Dr. Siemens had said that the Post Office was a department in the habit of spending millions. That might be so; nevertheless it possessed individuals who were in the habit of exercising all their talent and ingenuity in producing economy and efficiency in working. It was for that reason that he wished to direct the attention of the Institution to one portion of the apparatus which, he thought, exhibited great ingenuity. He referred to the valve. The tubes used in the radial system were worked, when the business was slight, intermittently, first by vacuum, and then by pressure; and where the business was great they were worked continuously both with pressure and with vacuum. It therefore became a question of considerable importance to devise a valve which should, in the hands of a messenger boy, enable them to work under these four conditions without

difficulty. The valve represented in Plate 5, Figs. 1, 2, and 3, had been in incessant work for twenty-one months. To obtain the four different objects required, with one simple manipulation, was an exceedingly difficult mechanical operation. A piece of lead pipe, that had been in constant use for twenty-one years between Telegraph Street and the Stock Exchange, had been worn to a beautiful smoothness, but there appeared to be no diminution in its thickness.

He now proposed to speak on his own behalf. It was twenty-one years since, as assistant to Mr. Latimer Clark, M. Inst. C.E., he first became connected with pneumatic telegraphy; and if experience justified the expression of opinion, an experience of twenty-one years would be a sufficient justification for his addressing the Institution. In the course of last autumn he had visited Brussels, Berlin, Vienna, and Paris, with the consent of the Postmaster-General, to inspect the telegraphic, especially the pneumatic, arrangements of those towns, and he would briefly state the results of that inspection. At Brussels, the pneumatic telegraph was simply employed in blowing messages from the counter to the instrument room at the top of the building. The same process was adopted to a considerable extent in London, there being no fewer than twelve post-offices where a simple blower was employed to drive the messages from the counter to the instrument room. At Berlin, pneumatic telegraphy had received a somewhat wider extension. Dr. Siemens had, on several occasions, described the working of that system. There were two such telegraphs in Berlin —one connecting the central telegraph station with the Bourse, 800 mètres in length, and the other with the Potsdam and Brandenburg Gates, 2,200 mètres long. Both were originally worked on Messrs. Siemens' continuous, or circuit system, consisting of two pipes, through which the air was driven in a continuous stream. He was not, however, much surprised to find that that method had been abandoned.

In Paris, the central station was situated on the "other side" of the Seine, in a position somewhat similar to that occupied by the Waterloo Station in London. There were altogether seventeen stations in Paris, connected by a length of 14 miles of pipes. There were three circuits, as shown in Fig. 4, p. 117. The system was worked by steam and by water. At the central station there were two steam-engines, one being in reserve. At the Rue de Boissy there was a water-compressing engine. The water from the mains was used to compress the air in a cylinder, and by a very ingenious contrivance also to produce a vacuum. The same thing

obtained at the Grand Hotel. At the Bourse and at the Great Northern Railway station, there was steam power. There were thus, in Paris, three separate and distinct steam-engines, and three separate and distinct water-engines. Trains were made up from the central station every quarter of an hour. There were seven stations to serve. Seven distinct carriers, with the names of the stations on them, were inserted in the tube. From the Rue de Boissy to the Bourse they were sucked by a vacuum, and from thence they were driven by pressure round the rest of their journey. There was thus a regular circulation of carriers throughout the whole city. The daily average of messages during the month of August was 7,404. He had not the exact statistics for Berlin; but he believed the number there was about 3,000 daily.

The Vienna system was almost identical with that adopted in Paris. At the central station there were two engines of 26 HP. each, one of which was kept in reserve. The engine worked pumps which compressed and exhausted air in four cylinders marked G, G, H, H (Plate 7). The pumps and cylinders were connected by a thick pipe with similar reservoirs at the Fleischmarkt Station, No. 2; so that the engine which exhausted and compressed the air at one station did the same thing at the other. There were also two engines in the Gumpendorf Station, marked C D, C D, which exhausted and compressed air in the cylinders G G, H H. Trains of seven carriers each were driven at regular intervals. They were forced in one direction by pressure, and drawn in the same direction by vacuum. At certain points—the Bourse, the Landstrasse Station, and another—there were single pipes, and the carriers were forced in one direction and drawn in the other. The system adopted at Vienna and Paris differed from that employed in London in two essential particulars. In the first place, the former system was the circuit, and the latter the radial. In the next place, throughout Paris and Vienna iron pipes were used. In deciding upon any pneumatic or telegraphic system, the first question the engineer had placed before him was that of speed of transmission. Without speed, telegraphy was almost useless. If it took as long to send a message from Great George Street to the City, as it would to send a commissionnaire, very little business would be taken to the wires. The Postal Telegraph department in London had decided that no message should occupy more than five minutes in transmission from one point to another. They had endeavoured to secure that rate of speed throughout the whole country, and had succeeded; and it was mainly owing to that fact that the number of messages had risen in five years

from 6,000,000 to upwards of 20,000,000. Whatever benefit there might be in the circuit system compared with the radial, it was also necessary to consider the adaptability of the two systems to particular places. The circuit system might be specially adapted to Paris, but it was altogether impracticable and inapplicable to London. In Paris, the chief telegraph station was not central at all, but was at the outskirts of the city. If it had been at the Bourse instead of at the Rue de Grenelle, several sides of a polygon might have been dispensed with, a length of no less than 10,622 mètres of pipes might have been saved, and the engine power could have been concentrated in one building. In London the stations, instead of being scattered as in Paris, were concentrated round the central station, and they were all distinct and independent of each other, requiring only communication with the central station. The average daily number of messages dealt with was 17,704; and considering the limit of speed adopted, the work could only be accomplished on the radial system. In Paris, a person might arrive at a station just after a train had left, and would have to wait a quarter of an hour before another was despatched, and then the transmission of his message to a short distance might occupy ten minutes more, and thus delay it twenty-five minutes. In Vienna it was still worse; there was often a delay of thirty-three minutes. People on the Continent did not appear to realise the desirability of cultivating great swiftness of transmission. In establishing the Parisian system, the problem solved was to insure that no message should exceed at the most an hour and a half in transmission. At Vienna, the messages were so much delayed that the people at the Bourse employed velocipedes; whereupon the authorities were compelled to lay down a distinct pipe, on the London system, to serve the Bourse. In fact, wherever the business on the Continent required it they were forced to adopt the radial system. To adopt the circuit system in London would be like taking a passenger, who wished to go from Great George Street to the City, round by Willesden Junction; or serving Dover, Hastings, Brighton, Southampton, and Bristol by a single line working through Reading.

In introducing lead pipes in London the authorities had not committed so great an offence as Dr. Siemens appeared to impute to them. No doubt the Post Office had spent millions for the benefit of the public; but many persons in connection with that establishment exercised their ingenuity in providing economical arrangements, and in introducing lead pipes instead of iron that policy had not been departed from. Dr. Siemens

had said that he could not employ iron casings to lead pipes in consequence of the extreme cost. What, however, were the facts of the case? Dr. Siemens' firm had laid iron pipes between the General Post Office and the Strand Station at a cost of 15*s.* a yard. The expense of the iron pipes laid in Paris had been 13*s.* 8*d.* per yard. At the time when the Messrs. Siemens were laying iron pipes between the City and the Strand, Messrs. Reid Brothers were laying lead pipes, cased with iron, at a cost of 13*s.* 3*d.* per yard. The average cost in London had been 12*s.* 8*d.* for a 2¼-inch lead pipe in a 3-inch iron casing. They had also 3-inch lead pipes in 4-inch iron casing, larger than any that the Messrs. Siemens had laid down, and the cost was 17*s.* 4*d.* per yard; so that the cost of the pneumatic system was not, as Dr. Siemens had stated, "several times" as much as the other. On the contrary, the London system was cheaper than the Continental. He might be permitted to state that the authorities had determined to put lead pipes inside those laid down by the Messrs. Siemens.

When the subject was first brought before the Institution, he had ventured to propound a theory as to the motion of air through tubes. He had on that occasion endeavoured to show that the motion of carriers through tubes was a function of the mass of air, rather than of its volume, that it was a case of uniform motion, and that it was in reality due to a difference of pressure. Mr. Culley and Mr. Sabine had endeavoured to prove that the motion of air was due to the expansion from the higher pressure to the lower. What, however, was expansion but simple motion? and to what was the motion due, if not to the difference of pressure? According to the molecular theory of gas, the molecules were in ceaseless motion, and it was their impact against the sides of the containing vessel, or their effort to get away from the position in which they were held, that constituted pressure. In fact the word "pressure" was indissolubly connected with the idea of motion imparted, or motion prevented; so that in saying that the motion of air was due to a difference of pressure, he endeavoured to "hark back," as it were, to the very foundation of the science, and to take up that branch of the motion of air which rendered it analogous to the motion of electricity and of heat. The motion of heat was due simply to a difference of temperature; the motion of electricity was due to a difference of potential; and in the same way, the motion of air was due simply to a difference of pressure; these terms being in reality analogous. He had pointed out that in a long pipe the

fall of the pressure was uniform. In Fig. 3, p. 81, it was shown that, in a certain way, that was not always the case; but that exception really proved the rule. The diagram rather exaggerated the difference between the real and the calculated pressure. The actual difference was due to the fact that, at the central station at Fenchurch Street the loop and the valves acted as a contraction of the pipe, and so heaped up, as it were, the pressure on one side and diminished the vacuum on the other. On the previous occasion Mr. Bramwell, not satisfied with his own knowledge of mathematics, had brought in the assistance of a senior wrangler, who had evolved a curve not agreeing with his (Mr. Preece's). The fact, however, was undeniable that the pressure on the tube, from beginning to end, fell inversely as the length of the tube, and was represented by a straight line. M. Bontemps had fully confirmed that view, which was also supported by the experiments of Messrs. Culley and Sabine. The reason why his theory had not been received was, that volume had been confounded with mass, and that the law of dry gases had been taken as applicable to damp gases. The gas in the pneumatic tubes was damp air, while the formulæ that had been given were applicable to dry gases. These differences were indications of how little was known of the true theory of the subject, and of how much there remained yet to be done to withdraw the subject from the region of speculation to the solid foundation of scientific truth.

Mr. Sauvee agreed in thinking that the pneumatic system adopted in Paris was better than the London one. The latter might, more justly, be called the City system, as it had been restricted (except in the Charing Cross line) to the City. Though a considerable saving might have been realised by connecting several of the offices nearest each other, thereby dispensing with double lines for each of those offices, the City system had been worked to the complete satisfaction of the business world, and did great credit to the engineers who designed it.

In speed pneumatic transmission could not of course compete with electricity, except where the number of messages was too great for the number of wires. Telegrams had in that case to wait their turn, and there was considerable delay in their transmission. But if used only for the speedy delivery of letters pneumatic transmission was invaluable. London, of all cities in the world, on account of its immense area and population, was the one where the pneumatic system might be worked to the greatest advantage. A net-work of five or six groups of circular lines, with head offices at Charing Cross or at the central office, might be sufficient. The

problem was how to deliver a letter from one end of the diameter of a circle of 4 miles radius to the other end, within half an hour at the utmost from the time it was posted. Dr. Siemens had, he believed, first proposed to the post-office authorities this scheme a few years ago. Since then, the researches of Messrs. Varley, Latimer Clark, Sabine, and others in England, and of Messrs. Bontemps and Crespin on the Continent, had fully demonstrated the practicability of establishing, for the transmission of letters, pneumatic lines combining rapidity in working with cheapness of first establishment.

According to his view the comparison by Mr. Preece between the Paris and Vienna systems and the City system was not correct either in principle or in fact. The principle of working the lines in Paris and in Vienna was different from that in London. In the former cities the trains collected and distributed the messages as they went their round, while in London the messages were all collected at one point and afterwards sent to their various destinations. This latter method must of course entail a great waste of power. Besides, in Vienna, there was no restriction as to the number of words in each telegram; and in this lay the great advantage of pneumatic transmission over electricity. In Paris it was intended to work the net-work as soon as completed on the principle of allowing for each message as many words as the form would hold.

When the Austrian Government desired to establish a pneumatic system in Vienna their Engineer visited Paris, London, and Berlin, and it was only after long and careful consideration that the circuit system had been adopted. Plate 7, Fig. 1, showed a plan of the Vienna system as it had been laid in 1874. There were in Vienna ten telegraph offices:—1, Central Office; 2, Post Office; 3, Taborstrasse; 4, Landstrasse; 5, Kärnthnerring; 6, Neumanngasse; 7, Gumpendorfer Strasse; 8, Mariahilf; 9, Mariatreu; 10, Stock Exchange. The offices Nos. 1 and 7, each placed about halfway on the main line, were the only two stations at which the machines were erected for working the whole of the system. The line had been laid underground in trenches 3 feet 4 inches deep, so as to be protected from the frost. The pipes were wrought-iron lap-welded tubes $2\frac{9}{16}$ inches interior diameter. The line proceeded from the Central Office No. 1 to No. 2, where it led to an apparatus constructed for the arrival and forwarding of the trains. From No. 2 the line started from an apparatus, similar to the other, and placed by the side of it, and led to the office No. 5, where it was similarly connected as at No. 2. From No. 5 it went to

No. 6, and from there to No. 7, which differed only from the preceding stations in the machinery for working the line, which was similar to that at No. 1; but the apparatus for receiving and for forwarding was the same; from No. 7 the line led to No. 8, then to No. 9, and arrived again at No. 1: it was, therefore, a kind of circular main line, which connected the offices Nos. 1, 2, 5, 6, 7, 8, and 9. In this line the trains always travelled in the same direction at regular intervals. The branch stations 3, 4, and 10, were in communication with the offices Nos. 1 and 2 on the main line, through branch lines. At the office No. 2 there were only pressure and vacuum reservoirs, which were in constant communication with those at the central office through two special lines of pipe.

The traffic was worked by trains at intervals of fifteen minutes, carrying away from each office the whole of the messages accumulated in the interval, and leaving at the same time all the messages addressed to the office which had been posted at the other offices up to the departure of the train, irrespective of their number. This method of working the pneumatic telegraph was entirely different to the one in use in London or Berlin. It could be seen at a glance how much simpler and cheaper the system adopted in Vienna was for laying the lines; the mode of working the traffic by trains at regular intervals was also considerably cheaper, and was very often more speedy than the electric telegraph, especially when there was a large increase in the number of messages within a very short time. The Vienna system, though very much resembling that adopted in Paris, was worked on a different plan in regard to pressure. The working pressure of the air in the reservoirs at the central station, and at No. 7, was 28 lbs.; the pressure in Paris being only 9½ lbs. Two-thirds of the distance between each station was worked with full pressure, and the last third by expansion, the mean working pressure being 22½ lbs. per square inch.

The various speeds obtained in pipes with an initial speed due to a mean pressure of 22½ lbs. to the square inch were shown in Plate 7, Fig. 3, which also recorded the time occupied by a train in travelling through, either by pressure or by vacuum, the full lines representing vacuum. The train starting from the central office at the hour would leave station No. 2 at $H + 1^m$; it would reach Kärnthnerring at $H + 2^m$, leave there at $H + 2\frac{1}{2}^m$, to be at Neumanngasse at $H + 3\frac{1}{2}^m$; and start from there at $H + 4^m$ by the Gumpendorf line, which was 1,739 yards long. This line would have been previously emptied of air by the vacuum pumps

at No. 7, and therefore the train would travel through it at a speed equal to that obtained in a line half that length, and it would arrive at office No. 7 in 1^m, or at $H + 5^m$, to start from it at $H + 5\frac{1}{2}^m$ for office No. 8, which it would reach at $H + 6\frac{1}{2}^m$; it would leave this station at $H + 7^m$, No. 9 at $H + 9^m$, and would return to the central office at $H + 10^m$; having thus completed the circuit in ten minutes. The train had therefore five minutes to spare before the next journey at $H + 15^m$. During that time the machine at the central office and the reservoirs at the Post Office (No. 2) would have worked the branch lines at offices Nos. 10, 3, and 4, by pressure or vacuum, and the journeys to and fro would have been completed between the passages of two trains on the main circuit. The work was done by a 15-HP. engine at the central station, and by a 9-HP. engine at No. 7, or 24 HP. for the whole system. The engines and pumps were in duplicate at each of these offices. The branch line from No. 1 to No. 10 was worked by vacuum. It was 450 yards long, and the distance was traversed in twelve seconds; about 50 yards a second. The carriers were similar to those used in Paris, viz., iron boxes covered with leather.

Of the schemes for working pneumatic lines between towns, one proposed between Paris and Versailles by M. Crespin, the well-known contractor for the pneumatic lines in Paris and Vienna, had received the approbation of the authorities. The line was double, 18 kilomètres long, and was divided into sixteen sections of 1,125 mètres. At A, B, and C (Plate 7, Fig. 4) were the engines and pumps to work the line; at station A, halfway between Paris and Versailles, were two 50-HP. engines, capable of exhausting in ten minutes 211 cubic mètres, and of compressing at the same time 141 cubic mètres of air at 14 lbs. pressure. This volume of compressed air corresponded to the whole length of 18 kilomètres. The engines at the head stations, B and C, were two of 25 HP. They worked pumps exhausting in ten minutes a length of 4,500 mètres of line, and compressing in the same time 900 cubic mètres of air, at 14 lbs. pressure. At these two stations the forwarding and the receiving apparatus were also erected. The large pressure reservoirs at A, B, and C were connected together by a cast-iron pipe 4½ inches in diameter, which was laid in the same trench as the pneumatic tube. A short link put into communication this pipe and the small pressure reservoirs holding 15 cubic mètres, erected close to the pressure relay at the end of each section. The line was exhausted by the three vacuum reservoirs at A, B, and C, and by two intermediary reservoirs at V and V_1, connected with

the large reservoir at A. The total capacity of the vacuum reservoirs was 280 cubic mètres. Each vacuum reservoir worked a vacuum relay. On Fig. 4, sixteen pressure relays and five vacuum relays were represented. To explain the working of the line, and the action of the pressure and vacuum relays, it must be supposed that the carrier or train of carriers was just on the point of starting from C. There was vacuum in front, and pressure at 14 lbs. per square inch was turned on behind; the carrier started under an effective pressure of about 28 lbs., with a mean speed of 40 mètres per second, and it soon reached pressure relay No. 1 (Figs. 5). Passing through it struck against the tappet, whose rod, *t*, knocked off the hook C. This released piston P and the slide-valve T attached to the piston-rod; the fall of piston P put the second link of the line in communication with the small pressure reservoir at No. 1, and the fresh supply of compressed air gave a new impetus to the carrier. The introduction of air at the back of the carrier was regulated by the other piston; the time it took to reach the top of its stroke being fixed, by opening the small cock *r* on the cover. As soon as the carrier had passed through the pressure relay No. 1 this piston began its up-stroke, and attained the top when the carrier arrived at No. 2 relay: the valve S attached to the rod of the piston followed it up and closed the communication between the line and the pressure relay. As the pressure decreased the piston P began to ascend, and the slide-valve T closed the communication between the pressure relay and the small pressure reservoir. At the top of the stroke piston P hooked itself up again, and the relay was ready for the passage of the next carrier.

The carrier passed successively through pressure relays 2, 3, and 4; but just in front of pressure relay No. 4 it passes through vacuum relay No. 1 (Figs. 6). In transit it struck tappet V, which unhooked the valve, and so closed the line behind, as shown in the diagram. The compressed air in the section just traversed by the carrier now escaped through the perforated part, M, of the tube in the relay and the escape valve N. The piston P descended and the sluice S closed, but as soon as the carrier had passed through, the valve was closed, the piston P was raised up, under the influence of the exhaust going on at the top of the cylinder, by means of the small tube *t*, and also under the influence of atmospheric pressure underneath. As it ascended it opened the sluice S, and thereby established communication between the vacuum reservoir and that part of the line on the left which was now filled with air at atmospheric pressure. The escape-valve N kept closed, and as

soon as the air was exhausted once more the piston P fell down and opened the valve. It took eight minutes to exhaust the first vacuum section, and the carrier reached vacuum relay No. 2 in two minutes only; so that when valve D was opened again exhaust had been going on in the second vacuum section during six minutes. To promote the down stroke of the piston P the difference in the degree of exhaust between two successive vacuum sections was regulated at about ½ lb. This was obtained by means of a vacuum regulator (Fig. 7). C C′ represented a short length of cast-iron pipe on the branch pipe connecting the vacuum reservoir with the vacuum relay; a slide-valve, T, was attached to the piston N, atmospheric pressure pushed up the piston and closed the valve; but the weight P kept the piston down as long as the degree of exhaust required had not been obtained.

Fig. 8 showed the apparatus for receiving or forwarding the carrier. When used for forwarding carriers the valve C was closed and the small door P open; the carrier or train of carriers was dropped into the tube, the door P closed, the tube in front of the carrier put into communication with the vacuum reservoirs, and pressure was turned on behind it. To help the carrier to pass the large cock R pressure might be introduced at the back of the carrier in the apparatus itself through the small cock *r*. When the apparatus was used for receiving the carriers at the end of their journey the valve C was open, and the train, on arriving in the receiving-box, P′, knocked, at the farther end of the box, against a suitable buffer, so as to deaden the shock; the valve C was then closed again, the large door opened, and the carrier or train of carriers removed.

Fig. 9 represented a carrier and a piston: they were both made of wrought iron: the carriers were provided at both ends with two collars of anti-friction metal. These rings were slightly rifled outside, like a gun, so as to impart a rotary motion to the carriers. This motion insured equal wearing of the rings, and removed any grit or dust that might impede the travelling of the carrier. The piston was hollow, with openings to catch the dust or rust that might be in the tube. Each train was composed of one piston and six carriers; and the weight of messages was from 12 lbs. to 14 lbs. Forty thousand messages could easily be forwarded in a day with trains every fifteen minutes.

Mr. J. W. Barry said when Mr. Carl Siemens' Paper was read four years ago, he had ventured to express a doubt as to the advisability and economy of transmitting messages by the pneumatic process from the City to Charing Cross, the dis-

tance being $1\frac{3}{4}$ mile, and the time occupied in transmission nine and a half minutes. He thought that to send a message (which had come from the Continent, Scotland, or any other distant place, at the extreme speed of telegraphy) through London at a speed of 20 or 30 miles an hour was not a system that would commend itself. It was now stated, however, that the pneumatic tubes were only to be applied in instances in which the distance between the stations in question and the central station was traversed in five minutes. It was obvious that there must be a point at which the pneumatic system ceased to be economical in point of either time or money; and he should have been glad if some better estimate had been given on that subject. With distances of $1\frac{1}{2}$ mile and $1\frac{3}{4}$ mile, he thought there could not be much economy, even of money, in sending messages by the pneumatic process. He was not alluding to letters, but to telegraphic despatches. The money question had been dealt with rather cursorily in the Paper. It had been said that, on the whole, the pneumatic system in London was more economical than transmission by wire. But the system dealt with in the Paper included both long and short circuits; it would be interesting to know the details of the estimate, and to separate the cost of the long circuit from that of the short circuit. In the case of a message from St. Martin's-le-Grand to Charing Cross, he could not help thinking that the pneumatic process would contrast unfavourably both in time and money with the wire. Mr. Culley had stated that the rate of sending telegraphic messages was one message per wire per minute, at an extreme speed, or one message per wire in two minutes for ordinary working throughout the day. If that was a correct statement it still appeared to him a mistake to throw away the three or four additional minutes required to traverse the five minutes' distance in question. It had been stated in the Paper that the public was very exacting in regard to the Post Office arrangements, but he must demur to that statement. It should be remembered that London was now worse off in regard to price than it was before the Post Office took to the telegraphs. Formerly it had the advantage of a sixpenny tariff; but now no telegram was sent for less than a shilling. He thought the sixpenny rate might be with advantage restored, or else some method adopted of transmitting a special class of expedited letters by the pneumatic process. He threw out these observations because the remarks he had made four years ago appeared, to some extent, to have been borne out by subsequent experience.

Professor Unwin desired to thank Mr. Sabine for the useful

information conveyed in the Paper. He had recorded a large number of experiments, which must have required industry and perseverance, and the results were, from a scientific point of view, exceedingly valuable. When the discussion on Pneumatic Tubes took place a few years ago, he pointed out that the theory of the motion of carriers in tubes, when worked continuously, resolved itself into this—that the work produced by the expansion of the air in the tube required to be equated to the frictional resistance of the air, and that the other resistances were so small that they might, at least for an approximation, be neglected. He had since learned that Mr. Sabine had anticipated him by twelve months or more in that view of the question, and that as early as 1870 he had published formulæ, based upon that mode of proceeding, which were substantially identical with those given by him on the present occasion. There was, however, this difference between his treatment of the problem and Mr. Sabine's. He stated his belief that the expansion of the air in the tubes would be isothermal, while Mr. Sabine assumed it was adiabatic. Four years ago he had given the same reason for assuming the expansion to be isothermal, which Dr. Siemens recently stated so very clearly. After Mr. Sabine's own experiments, and those of M. Bontemps, he thought there could be no doubt that the expansion of the air in the tubes was nearly isothermal. He did not think it made any great difference in determining the transit time of the carrier, whether it was assumed to be isothermal or adiabatic, but it would make more difference in estimating the power required to propel the carriers through the tube. If the adiabatic law led to simplicity of formulæ, there might be some reason for adopting it; but the reverse was the case, for the formulæ were more simple, assuming the expansion to be isothermal, than in assuming it to be adiabatic. There was another point which he thought of still more importance. The whole of the work, obtained by the expansion of the air in the tube, was expended in overcoming the friction of the air against the tube, with a very small exception. To obtain an estimate of the friction of the air in the tube, it was needful to find an expression for the friction of a short length of the tube in terms of the velocity, and to integrate that expression for the whole length. Mr. Sabine had proceeded in a different way; he had practically assumed that the air had, at every point of the tube, exactly the same velocity, namely, the mean velocity for the whole length. If there were no great difference of velocity at different parts of the tube, this proceeding would lead to a

sensibly correct result; but he found on examination—and it was confirmed by what Mr. Carl Siemens had said in his Paper —that there was a great difference in the velocity. The carrier started at a comparatively low speed, and attained the highest velocity at that part of the tube where the pressure was least (Fig. 30), and in that case it was not accurate to assume that a constant mean velocity might be substituted for the integration of velocity through the length of the tube. It had appeared to him that it would be worth while to try the result, first, of

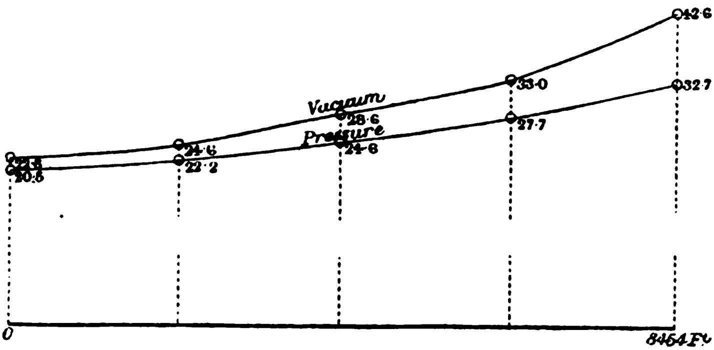


Fig. 30.—Curves of Velocity in feet per second.[1]

assuming that the law of expansion was isothermal; and, secondly, of attempting the integration of the friction corresponding to the different velocities in different parts of the tube, and he had obtained, in that way, some expressions which he should be happy to place at the service of the Institution. Mr. Sabine had tested his formulæ only in one way. He had ascertained from the experiments the values of the constants in his formulæ, and then using those constants he had deduced the transit time for the whole length of tube. The agreement in this respect between the formulæ and experiment was certainly very good. Professor Unwin had this and two other tests of his formulæ. In the first place, he found that they agreed as well as Mr. Sabine's with the experiments in giving the transit time for the whole length of the tube; and in the next place, he had been able, by their aid, to draw curves of pressure for the whole length of the tube. The diagram (Fig. 31) showed the curves of pressure which he had obtained for the two experiments narrated in the Paper. It would

[1] These curves are for the same data as those given by Mr. Sabine, p. 80, and may be compared with Fig. 3.

be seen that at every point the theoretical pressure in the tube rose above the straight line between the two terminal points, and that agreed entirely with Mr. Sabine's results. Mr. Preece had previously stated that the fall of pressure followed such a law, that it could be represented by a straight line, and he appealed to the diagram in proof of that statement. No doubt if air were incompressible, the fall of pressure would occur in a straight line; but, as it was not, it was impossible that it should do so, and it was rather extraordinary that a diagram exhibited by Mr. Sabine to prove that the fall was not in a straight line, should be appealed to as a confirmation of the

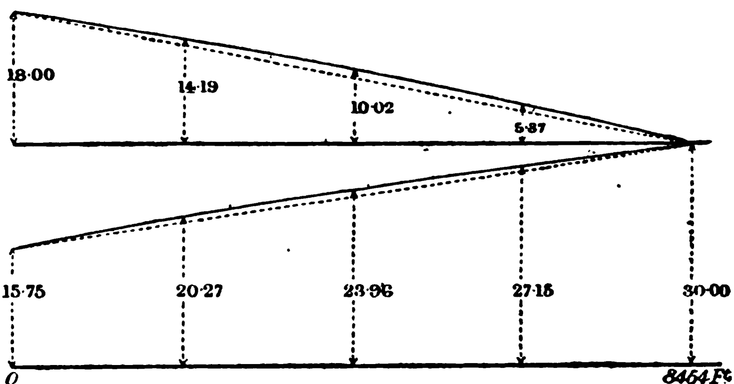


Fig. 31.—Curves of Pressure in inches of Mercury.[1]

contrary assumption. In the third place, he had obtained curves of velocity in different parts of the tube, which showed precisely, as Dr. Siemens had formerly stated, that the velocity increased very much towards the terminal end of the tube. Mr. Sabine would, he thought, see that in another point those results were beyond what he had obtained. He did not think that Mr. Sabine's formulæ would give the time of transit over an intermediate portion of the tube. He next came to a point of even greater importance. An estimate had been given of the work expended in driving the carriers through the tubes—first the work expended when the tube was under pressure, and according to a perfectly correct method; but in the examination into the work expended when the tube was under vacuum, a very different method had been adopted. It was stated that the working of the pump

[1] These curves are for the same data as those given by Mr. Sabine, p. 80, and may be compared with Fig. 3.

in the vacuum tube was much more simple than when the carrier was driven by pressure. He was entirely unable to see any difference between taking air out of the atmosphere at 15 lbs. pressure, compressing it to 30 and then forcing it into a tube, and taking the air out of the tube, say at 9 lbs. pressure, compressing it, and then forcing it into the atmosphere. The two ways of dealing with the air were identical, and the expression which gave the work required in one case, would be identical with the expression for the work required in the other case. Mr. Sabine, however, obtained for the vacuum tube a totally different expression from that which he used for the case of the pressure tube. He thought that the error had arisen from finding the work done in one stroke of the vacuum pump and neglecting the return stroke. He had calculated rightly enough the work done by the piston of the vacuum pump while it was drawing air from the pneumatic tube; but he had apparently forgotten that, in the return stroke of the pump, the atmosphere did work upon the piston above what was necessary to force the air in the cylinder into the atmosphere, and that that surplus work, in any properly-constructed pump, was stored up. The result of what appeared to him to be a very considerable miscalculation was, that Mr. Sabine had very much overestimated the work expended in the case of a vacuum pump. He arrived at the conclusion that it was equally economical to work the pump by pressure and by vacuum. If, as Professor Unwin believed, he had overstated the work of the vacuum pump, that conclusion was erroneous, and it was more economical to work the tubes by vacuum than by pressure. It might be remembered that Mr. Bramwell suggested that it would be economical to employ a lighter gas than atmospheric air—that much less work would be required if the tubes were filled with hydrogen than would be required if they were filled with ordinary air. The same principle would show that, when the tubes were filled with air of less density than the common air, they would work more economically than with air which, on an average, was of greater density than the common air. In London, of course, the prime necessity was speed of transit, the power consumed being a matter of secondary importance; but if the pneumatic tubes came to be used, not merely for sending messages to short distances in very small tubes, but on a larger scale, it would become a question whether, if hydrogen could not be used, at least air of less density than the common air might be. He had been too much occupied to make any exact calculation, and he only threw out the sug-

gestion that an improvement might be effected in the working of a tube, like that to Charing Cross, in the way he had mentioned. As originally constructed, it was a single tube which went to Charing Cross and back again. At the end of it there was a pump which took the air out at one end of the tube and pumped it into the other end. If, at starting, the whole of the tube contained air of ordinary atmospheric pressure, the effect of starting the pump was that the pressure at one end of the tube became greater than atmospheric pressure, while that at the other end became less than atmospheric pressure. But if, before starting the pump, the whole of the air in the circuit had been reduced to a tension of one-half, or one-quarter, of atmospheric tension, the work of the whole of the tubes would be done with a very much less weight of air; and in that case it would be found that there was an economy of power. He did not know that there would be any sufficient gain, because a somewhat more complicated apparatus would be required; but, so far as concerned economy of power, a saving would be effected. Of course it might be replied that, if, initially, some of the air in the tubes were abstracted, the leakage at the points where the messages were introduced would soon bring the whole of the air in the tubes up to the density of ordinary atmospheric air. That, no doubt, would be so if no provision were made to prevent it. If tubes were to be worked with air of less than atmospheric density, in addition to the ordinary pump, which took the air from one end of the tube and drove it into the other, a special pump would be needed, whose function would be to maintain the proper density of the air in the tubes; but he did not think that that presented any particular difficulty.[1]

Dr. SIEMENS desired to congratulate the Institution upon the very lucid explanation and scientific exposé of Professor Unwin, with every word of which he agreed. He had already discussed Mr. Sabine's Paper, but now proposed to offer a few remarks on the theoretical principle involved in M. Bontemps' communication. An interesting account had been given of experiments to determine the velocity of carriers in pneumatic tubes by electrical markers, with records of the observations on a chronograph. The results thus obtained must, he thought, be accepted as indisputable; but he was inclined to doubt some of the generalisations attempted in the Paper. It was perfectly true that when two carriers followed one another in a tube worked by

[1] *Vide* p. 263, *et seq.*

a continuous current, the time occupied by each carrier in traversing the same section of the tube from one marker to another must be the same, because the current flowing through the tube was always the same; but it did not follow that the absolute speed, the number of feet traversed per second, should be the same in each portion of the tube. M. Bontemps appeared to have found that that was substantially the case—that after a short period of acceleration, the speed of the carrier fell into a uniform rate until almost the very end of the journey, when it again increased, and he stated that these results seemed to verify Fournier's theorem, according to which "equal impulses given throughout the journey of an accelerated body must produce the same velocity." These results did not coincide with the common-sense view of an elastic fluid expanding behind a light working piston, but he thought that an explanation of the experimental results was nevertheless possible. The air, say of 2 atmospheres pressure at one end expanded down gradually to atmospheric pressure, and the same index of air between the two carriers must elongate as the carriers went along; and expansion must take place throughout the course because working power was required at every point. But in taking the case of a carrier not fitting the tube entirely, and yet causing some friction against the sides, he should expect the results which were stated in the Paper. In that case the impulse given to the carrier in the tube would be carried by the rush of air past it, and this would be the same throughout, and there would practically be the same power active to overcome friction at every step of the course. The result would be a uniform speed for the chief part of the course, till the very end, when the rush of air past the piston would greatly increase. It was to be hoped that the Author would continue his observations with the appliances he had made in order to obtain further information on the interesting subject of gaseous friction in long tubes. An explanation had been attempted by Mr. Preece, of the apparent sluggishness of the air to expand throughout its course, by the fact that the medium was not pure air, but air mixed with vapour of water, which mixture would follow another law of expansion than that of either fluid taken separately. He dissented entirely from that view of the case. He had shown, and Professor Unwin had quite confirmed that view, that the air expanded isothermally—that both air and vapour would pass through a tube without altering in temperature; therefore no condensation of the vapour would take place; and as vapour and air both followed the law of Mariotte in precisely the same manner,

there could be no difference whether dry air was used or air containing a slight proportion of vapour.

In advocating the use of the radial system in preference to the continuous or circuit system, Mr. Preece said that he had travelled over the continent of Europe with a view of ascertaining the working of those systems elsewhere; and that, while he found the radial system established in Brussels, he ascertained that at Berlin the circuit system, which had been adopted in 1863, had failed. This was startling news to him; because, although he had never described the system as established at Berlin, he had referred to it, and his brother also had referred to it, in his Paper, as an historical step towards the accomplishment of the circuit or continuous system as established by them in London. He accordingly wrote to Berlin for information, and he had ascertained that, so far from the system having failed there, it had been during the last twelve years in uninterrupted operation, and that the only thing that could be construed into a partial failure was the circumstance that after the one circuit from the telegraph office to the Bourse had been established, a second circuit from the telegraph office to the Brandenburg Thor was added, and it had been found that the boiler power was not sufficient to work both systems continuously together. For a time, therefore, and probably at the very time when Mr. Preece paid his visit to Berlin, the one system was shut off when the other was worked between the telegraph station and the Exchange during the busy part of the day. With that exception, which he understood had since been set right by the addition of boiler power, the system had been working precisely in the same manner as it had been established twelve years ago, and it had given no cause of complaint nor inconvenience in the working. Mr. Preece further stated that the cost of the iron pipes, in connection with the circuit system as established in London, was at any rate higher than the cost of the system of tubes advocated by the Engineers at the Post Office, and that his (Dr. Siemens') firm charged for the iron pipe at the rate of 15*s.* per yard, whereas another contractor had laid lead pipes at a rate of 13*s.* 8*d.* He would not dispute those figures, but Mr. Preece had fallen into the error of making, no doubt unintentionally, a very unfair comparison. In the first place, he compared a 3-inch tube with a tube of much less diameter; he was not quite certain whether it was a 1½-inch or a 2¼-inch tube that he referred to as having been laid for 13*s.* 8*d.* He also compared a mere tube which had been laid in connection with an established apparatus, with the system of tubes

and instruments, carriers and other matters, required to constitute a complete circuit system. In the one case the instruments, carriers, and station fittings were not included in the estimate, and in the other they were included. There were also to be added in the case of the circuit system the engineering and general expenses which fell upon his firm in designing, making, and laying down the new system in London. He was employed as Engineer of the Post Office in designing not only the tube, but also the engines, boilers, reservoirs, and pumping machinery to work the system, and the contracts were let to three firms:—Messrs. Easton and Amos, who made the engines and pumping apparatus; Messrs. Aird, who laid the tubes and completed the earthworks; and Messrs. Siemens Brothers, who made the other mechanical arrangements. It should also be stated that as the system had been matured by his firm at great expense, and patented, they had a perfect right to superadd to their cost a reasonable amount for patent right. Including all the charges the Post Office paid for the first circuit the sum of £5,212, which was at the rate of 15*s*. per yard; but of this sum £2,900 were paid for the tube and the earthwork, including Mr. Aird's profit on the latter, all the rest being taken up by other work. Thus the figures for comparison were 8*s*. 4*d*. per yard for a 3-inch iron pipe, as against 13*s*. 8*d*. per yard for a lead tube of about half that area, which figures fully justified, he thought, his former argument. Mr. Preece likewise stated, that although the continuous or circuit system of working might be suited for such places as Paris, Vienna, and Berlin, it would never do for London, where speed was a principal object. He should be very sorry to have put forward for London a system that was not capable of the greatest development of speed, knowing as he did the value of time. But Mr. Preece, in describing the advantages of the radial system, seemed to forget that the two principal distances worked by the Post Office at the present time were worked on the continuous system, in exact accordance with the principles laid down by himself. All that had been done in the first circuit laid down by him was to take out about 3 yards of pipe at the neutral point at Charing Cross. One branch was worked by pressure, the other by a corresponding vacuum, and at the extreme point the pressure was neutral, so that the connecting link between the two sides might be taken out with impunity without altering the system in the least. The only difference would be that instead of bringing the same air back to Telegraph Street or to the General Post Office, there would be air which had travelled through the instrument room at Charing Cross and which had taken up a good

deal of vapour from the numerous persons engaged there, giving rise, probably, in a measure to the inconvenience of rust in the iron tubes; an inconvenience which had not made itself felt in Paris, Vienna, or Berlin, where iron tubes were used. He thought that with proper care that might be completely prevented in London. He admitted that it would have been expedient—indeed, he proposed it at the time—to have the inside of the iron tubes tinned, which would have given all the advantages of the lead tube coupled with the comparative cheapness of iron tubes. Mr. Preece seemed to imply that a circuit system of iron tubes was a roundabout system by which, in order to get from Charing Cross to Telegraph Street, it would be necessary to go round by Islington. That was not the case, nor had he proposed any such thing in laying down the first circuit between those places. The continuous system, if worked in circuits, could be so arranged that the distances between the two principal points on the circuit would be minimum distances, even though the intermediate stations might be a considerable distance apart. If a tube were established on the circuit system between Great George Street and the City, one branch might pass by the Strand, or the Embankment, and the other over the bridges through Southwark: both would be equally near, and the intermediate stations upon the two branches would be a considerable distance from each other, and be thus accommodated by pneumatic communication without increasing the time of transit between the principal stations, and without involving an extra consumption of air or power. On the whole, he thought that the radial system was well adapted for very short distances, and for very light carriers. If the object was to collect telegraphic messages from the streets immediately adjoining St. Martin's-le-Grand, it would be absurd to speak of establishing a circuit system, and Messrs. Clark and Varley had established that communication in a very efficient way. But whenever it was desired to carry pneumatic communication beyond those limits, to extend it over considerable spaces, so that not only a few offices in the City, but the whole of the metropolis might derive benefit from it, it would be absolutely necessary to resort to some such system as he had advocated.

Mr. Bramwell remarked that he wished to say a few words upon the question of the laws which govern the motion of elastic fluids, such as air, through pipes. He thought it might be taken that for the purpose of transmitting telegraph messages through pipes by the pressure of air, or by the exhaustion of air, the power required for the friction of the pistons, and even for setting the air

in motion, was so little that the resistance might be regarded as practically a simple question of skin resistance, or friction of the air against the interior of the pipes. If any corroboration of that view were wanted, it would be found in this Paper, where there was a statement of the relative speeds of transit through a 3-inch tube and through a 1½-inch tube under equal pressures. Through the 3-inch tube the time occupied was one hundred seconds, and through the 1½-inch tube, one hundred and forty-one seconds. Taking equal pressures upon the tubes, the proportionate velocities ought (if the resistance was a skin resistance only) to be as the square roots of the diameters of the pipes. The speed in the small tube was $\frac{10}{14}$ of that in the large tube; and if that were squared, it would give $\frac{100}{196}$; or, in round numbers, one to two.

There was a statement in the Paper upon which certain propositions had been founded, which statement and propositions he feared were likely to mislead. It was said that the power required to work a tube of 3-inches diameter would be 100, while the power required for a tube of 1½-inch diameter would be only 18. He thought it would be found that that was not so; for although these figures might truly represent the proportion between the horse-power of the two engines required under the two different circumstances, nevertheless, as looking at the respective velocities in the 1½-inch and 3-inch tubes already stated, the smaller sized engine would have to work to transmit a message for a given distance during a time represented by 141, while the larger power to transmit a message to the same distance would only have to work during a time equal to 100; the comparative final results in power expended would be as $100 \times 100 = 10,000$ for the 3-inch tube, to $18 \times 141 = 2,538$, or in the proportion of 100 to 25, as might have been expected. Therefore any calculation based upon the saving of power in the proportion of 100 to 18 was erroneous. It should be in the proportion of 100 to 25. Another statement, by its incompleteness, was also misleading: viz., that the water was used in the air-pump for lubrication. No doubt it did lubricate; but it was also used for a different and for a much more beneficial purpose—that of diminishing the extra resistance caused by the heat given forth in the pump before the opening of the discharge-valve, which heat enlarged the volume of the air, and (if not removed) would involve the expenditure of extra power to discharge the augmented bulk; but if that heat were put into water, the air was reduced to its true bulk, and the demand for power was diminished. He had been apprenticed to a member of the Institution named Hague, who, nearly half a century ago, was the inventor of a mode

of transmitting power to distances of ½ mile and ¾ mile, by the exhaustion of air. At the end of the exhausting pipe he put an engine, something like a steam-engine. Atmospheric air drove the engine, and thus did the required work at a distance from the motive power. The pumps used were exhausting, not compressing pumps, but the air, which on expanding after passing through the engine became cooled, was brought back again to the atmospheric temperature in its passage (in an attenuated condition) along the pipes, and then, on being compressed in the pump to atmospheric density so as to be capable of opening the discharge-valve, gave forth the heat in a sensible form which it had absorbed while in transit, and thus augmented the volume of the air, and added to the power required to work the pump. He believed it was himself who first suggested that it would be desirable to put into those pumps (for the purpose of getting rid of the heat) a small injection of water. That was done forty years ago. They did not use many indicators in those days; but this rough result was obtained, that whereas the steam-engine working the air-pump would only make twenty-seven revolutions when working without the injection, it would make thirty revolutions with it. Looking at the utility of injection as a means of saving power, it was a pity that a statement should be made, leading to the inference that the only object of the water in the pump was for lubrication. It had been suggested, when a similar subject was under discussion four years ago, that the fall of pressure in a pipe through which there was a flow of air, for such purposes as were then under consideration, might, in a diagram, be represented by a straight line. Mr. Bramwell ventured at that time to say that, though he had not sufficient mathematical power to determine what the line should be, he felt certain it could not be a straight one, and he gave his reason for that opinion. The speaker alluded to, however, now reiterated his queries, and had the hardihood, in order to prove his straight-line theory, to refer to a diagram put forward by the Authors of the Paper, which diagram showed conclusively that the fall of pressure was not represented by a straight line, but by a curve. The reason that he gave was rather astonishing. It would have been, he said, a straight line except for certain circumstances, which were as follows: "The difference was due to the fact that at the central station at Fenchurch Street the loop and the valves acted as a contraction of the pipe, and so heaped up, as it were, the pressure on one side, and diminished the vacuum on the other." But what did the Authors of the Paper say? That there was not any obstruction at the turning point, but that they had put in at

Fenchurch Street a carefully-prepared curve-piece. Moreover, if there had been obstruction, he did not agree that the effect of it would have been to heap up pressure. Those who had heard Mr. Froude's address to Section G of the British Association, at Bristol, would remember that he not only stated, but proved conclusively by experiment, that the place where there was the least pressure in a pipe through which water was flowing, was where the pipe was smallest. He had ventured to exhibit a diagram (Fig. 32), showing, as he thought, the true curve of pressure, and he was glad to see that the curve drawn by Professor Unwin justified that diagram. He was speaking, as on a former occasion, not of any intermittent motion of air, but of uninterrupted motion, and of the fall of pressure that would take place in tubes through which there was a continuous current, as in the case of the circuit system representing that fall. Under these circumstances it appeared

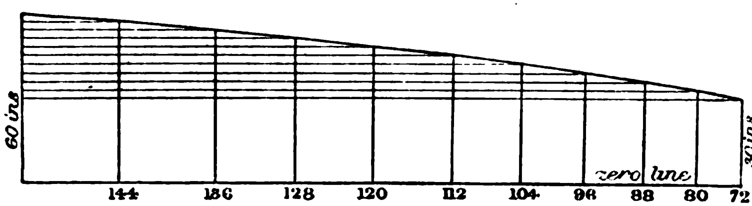


Fig. 32.

to him that the curve must be a parabola. The resistance, he believed, might be taken to be practically a skin resistance, which varied as the square of the speed, and inversely as the density. If, therefore, in any portion of the pipe, there was a density of 1, and a speed of 1 in a given time, there would be a resistance of 1; but if, in any other part of the pipe, the air had so expanded that there was only a density of $\frac{1}{2}$, there must be a speed of 2. But a speed of 2, with equal density, would give a resistance of 4; but being only half the density, it would give a resistance of 2; therefore the resistances increased directly with the diminution of pressure. That condition of things, he thought, could only be satisfied by a parabolic curve. He had found difficulty in determining what would be the fall in pressure at equal distances along the pipe; but he soon found that a very simple calculation sufficed to ascertain what would be the varied distances from pressure-gauge to pressure-gauge which would give uniform falls of pressure, and this mode of treatment showed that the curve was a parabola. The diagram he had placed upon the wall showed a supposititious pipe 1,080 yards

long, with, at one end, a pressure of 60 inches above zero, and at the other a pressure of 30 inches above zero; and if pressure-guages were inserted at distances increasing in an arithmetical ratio from the one end to the other, there would be a uniform drop of pressure at each gauge. Upon these principles the curve would be a parabola, and that would fulfil the conditions he had given. Another necessary condition was this: if the total difference between the pressure at one end and the pressure at the other above zero were ascertained, then the two terminal distances should bear the same relation to each other as the two terminal pressures. It would be seen by the diagram that, with 60 inches pressure at one end of the pipe, and 30 at the other, the two pressure-gauges, the first and the last, were 72 feet, and 144 feet from their respective ends of the pipes. He believed that a parabolic curve having its vertex on the zero line would fulfil every condition arising under a steady flow, but would not do so where there was an intermittent flow. Where there was such a flow and a sort of popgun action, the circumstances were very complex and difficult to investigate. For instance, M. Bontemps, in his Paper, had pointed out that, on the opening of the cock, the pressure-gauge fell, and afterwards rose a little, but never to its full extent. One could well understand why that should be. The air issued out of the vessel S under great pressure, and there being only atmospheric pressure to resist it, at first came out with great velocity, but it speedily found further resistances, viz., the inertia, and the friction of the atmospheric air in the tube, which resistances, as it were, heaped the air up. The air was elastic, and after the first shock it recoiled. This, he thought, might be the solution of the fact observed by M. Bontemps, that there was a period during which the speed was less than either at the beginning or at the end of the motion. To show the difficulties experienced in dealing with the question of the intermittent flow of elastic fluids, he (Mr. Bramwell) might be permitted again to direct attention to an experiment made by him, some years ago, on the South-Western railway, when trying Le Chatelier's Contre-vapeur system, which showed that with an aeriform fluid, there might be the same ram-action as with a water-ram; and that it was possible to get a higher pressure from the injection of a stream of elastic fluid under pressure into a space than the pressure in the vessel from which that fluid proceeded. In the instance in question a pressure had been obtained in the cylinders of a locomotive of 160 lbs. on the inch (and it might have been higher, but the indicator would not register it), while the pressure in the boiler was only 140 lbs. Many in-

stances had come under his notice where the steam was reversed, as in the case of the colliery winding engines, in order to bring them to rest when the cage was approaching the top, and where the indicator diagrams showed a similar effect of a pressure in the cylinder above that in the boiler from which the steam proceeded.

He would now call attention to an error into which M. Bontemps appeared to have fallen. He understood him to say that because when piston No. 2 was put into the pipe six seconds after No. 1 the pistons traversed past the indicating point at intervals of six seconds, this uniformity of time in passing proved that the air contained between those pistons did not alter its volume, and thus (M. Bontemps argued) it was shown that there was no expansion, and that the air behaved like a non-elastic fluid. He, however, thought the conclusion drawn by M. Bontemps was entirely erroneous, as he would endeavour to show by an illustration. If he dropped off the edge of the table six marbles, with a second interval between each, they would arrive at the ground with a second interval between each marble, but they would go at much greater speed when they did arrive than when they started; and if the distances between any two of those marbles were taken any part of the way down, it would be found that they were much farther apart near the ground than they were just after leaving the table. Therefore the fact that the pistons passed given points at equal intervals of time, whether those points were near the beginning of the journey or near the ending, was entirely consistent, and was just what should happen with the expansion of air between the two pistons.

He was glad to hear Professor Unwin make the suggestion, that in lieu of using pipes charged with hydrogen, it would be better to have them worked below the full pressure of the atmosphere. It was clear to his mind that as resistance was due to the velocity and to the density, it was a most desirable thing that the density should be as low as possible; and probably a ready mode of reducing resistance would be to keep the stream at half atmospheric pressure at one end, and at a quarter at the other, rather than to keep it at full atmospheric pressure at one end and at half at the other, because the reduction in density would so diminish the power required to draw the air through, that there would not be needed anything like the difference of pressure at the lower density that would be needed at the higher. Probably there would be in-draughts of air, and leakages; but he doubted whether the power required for a constant expulsion of air from

the pipes to maintain a general vacuous condition would not be below that which would be saved by having the tubes in that partially vacuous condition throughout. The circuit system of Dr. Siemens was peculiarly adapted to such a system, and also to the use of a lighter gas—such as hydrogen. He was glad that the haze which had been thrown upon the question, by those who took part in the discussion previously, had been cleared up by Dr. Siemens. Many must have believed that the circuit system of Dr. Siemens was such a one as that used in Paris, where a train of carriers was made up and despatched once in a quarter of an hour, the train being stopped at the different stations, and despatched again when the carrier for that particular station had been taken out. Those who remembered the Paper of Mr. Carl Siemens would know that no such clumsy expedient was contemplated. The very essence of the system was that there should be an air rope, as it were, always running through the pipes, and always running in one direction, that the carrier could be "hooked" on to that air rope whenever it was necessary, and that it could be "unhooked" at any station. Therefore to compare the time occupied in the circuit system adopted at Paris, with the time occupied with the system explained to the members of the Institution four years ago, was misleading. He believed it was not understood, until it had been explained that evening, that although there was in the case of the pipes from the Central Station to Charing Cross and back a break of a few yards at a point where there was uniformity of pressure within and without the pipe, nevertheless there was a constant current going in one direction, and a constant current coming back in the other; so that, in truth, the essence of Dr. Siemens' system was adopted. The only thing wanting was the connecting link at the place where there was no strain—no pressure either outwards or inwards.

Mr. COWPER observed that he was much pleased to hear the remarks of Professor Unwin with regard to the expansion of the air, showing how the distance between the carriers increased as they came out at the end of the pipe. It would be a great pity if the idea should prevail that the expansion of air in tubes was not understood. There might be slight differences as to the precise formulæ for calculating the exact speed or resistance; but that the air did expand, and issue much faster than it entered, was so clear, that he could not comprehend how M. Bontemps could reiterate the statement that two despatches kept their distance throughout the whole length, or speak of their attaining a uniform velocity, and keeping it up to the end. He himself said in another part of

his Paper: "The conclusion from these results is, that the slight augmentation of speed towards the end of the journey is due," &c., admitting that there was a slight augmentation; yet the whole Paper was based upon the argument that the carrier went at a uniform speed. Mr. Sabine had given a curve of true expansion, or true compression, and he stated that the same curve would represent nearly the compression or the expansion of the air. That again merely showed that the air did expand, and go faster at the exit than at the entrance. How any one could regard it as a proof of uniform velocity he could not imagine. As far back as 1855 he was called upon by Sir Rowland Hill, jointly with Mr. Gregory, to see what could be done to accelerate the mails. The matter was discussed, and it was hoped that 100 miles an hour could be accomplished. He had arranged for tubes with carriers packed with leather that would go 90 miles an hour, but it would have been at an extreme cost. It would have required an 18-inch tube, filled with a light moving power, viz., a partial vacuum. He agreed with what had been said as to the advantage of a light propelling medium. Mr. Gregory found that a much higher velocity could be attained with air in a more rarefied state than the ordinary atmosphere. Dr. Siemens, in one of his earliest descriptions of his invention before 1866, referred to hydrogen, or any other light gas, as being useful in the pipe; and he believed it was mentioned in his patent. The great friction of air in the tube was no doubt that which had to be overcome. It was not chiefly the piston, even if it weighed, as in Paris, 19 ounces; and with a light piston, the power required to drive it was as nothing. If greater velocity was needed, the tubes must be enlarged, and the air rarefied. He might mention an experiment made by himself, through the kindness of Mr. Latimer Clark, at Lothbury. The experiment was first tried with a tube as ordinarily used, with vacuum reservoirs and pumps at one end, and open at the other. When the despatch was put in, the reservoir was opened to the pipe, and exhaustion commenced. When this had gone on a little while, the piston soon started, and went through the tube. The utmost speed that could be obtained was 36 miles an hour. The pipe was then partially exhausted. There being no valve to the pipe, he put the piston in first, and plugged the end, exhausted the pipe, and pulled out the plug suddenly. In that way a speed of 51¼ miles an hour had been obtained with only a 1½-inch tube. The length of the pipe was ⅓ mile. That showed that any light medium, such as hydrogen or rarefied air, was more effective for propulsion than ordinary

air. The speed of 90 miles an hour, with large tubes and long lengths, could only be obtained by vacuum, not by pressure. Relays of reservoirs would be required every ½ mile, and engines every 4 miles. Sir Rowland Hill thought that the expense would be far too great, either for London or for Crewe and Holyhead. He accordingly advised him to accelerate the mail very considerably, and hence the "Wild Irishman." He then suggested an extra charge for express despatches in London, but Sir Rowland Hill was so fond of the penny post that he would not think of a *4d.* or *6d.* tariff. With ten pipes, or a total of about 39 miles in length, the whole of London could be fairly served, so that no part would be more than ½ mile from one of the stations. All the populous part of London, with about eighty-two despatch offices, would be well served, and there would be a more speedy delivery of letters than at the present time. There had been a good deal of discussion about half-hour deliveries, but that would give only a fractional saving over the two and a half or three hours during which letters now remained in the hands of the Post Office. If, however, tubular lines were laid and an extra price charged, the letters might be delivered by boys as soon as they were received. There was one point in the tables to which he took exception. He thought it was unwise to discard the reservoir for cooling the air. He would put a cooler, if cold water was accessible, for the condensing engine, and would first make it do duty by cooling the air below dew-point, causing it to deposit as much moisture as possible. He believed it was an error to take so narrow a view of the transit of despatches through the tubes, as though the question related only to the sending of one despatch, it being of no consequence whether there was a continuous supply of air, or a rope, as Mr. Bramwell called it, so as to take a large number of despatches. It was important to make the pipes do as much duty as possible, as they were expensive implements. One pipe was quite enough for one street, and it should take as many despatches as possible. If a pipe could be made to go one way and to come back another, serving two districts instead of only one, and at good speed, a great advantage would be gained. A despatch from a distant station might not reach its destination by the shortest way; but it would always go quickly, and the pipe would do much more duty than if it went straight from one point to another. He thought, therefore, that the advantages of the continuous over the radial system were very great. The Authors of the Paper had stated: "Where despatch is not of paramount importance, the circular system has advantages, by giving com-

munication between each station on the route." That was really required; and if the public only knew how it could be done, and what profit would be yielded by it, they would be a little more exacting in their demands than they were at present. As it was, only a few merchants in the City got the benefit of the radial system. The footpath in Cheapside was at present full of pipes, and some pipes were obliged to be taken through Gresham Street. There were twenty-four pipes, and a length of only 17 miles and a very few centres. With ten circuits eighty-two stations might be supplied, and the whole of London well served. He hoped to see further extensions of the Tubular Despatch system, believing it would be for the benefit of London, and of the Post Office exchequer.

Mr. Imray observed that he considered M. Bontemps had conceived erroneous views of the results of his experiments. He had given it to be understood that air behaved differently from any other elastic fluid—indeed, almost as an inelastic fluid; and he attempted to account for it by the presence of vapour, and otherwise. But it would be seen that air in the tube behaved precisely as an elastic fluid ought to behave. He would direct attention to a diagram (Fig. 33), showing the velocities according to M. Bontemps'

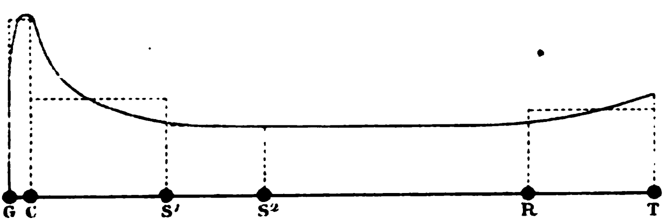
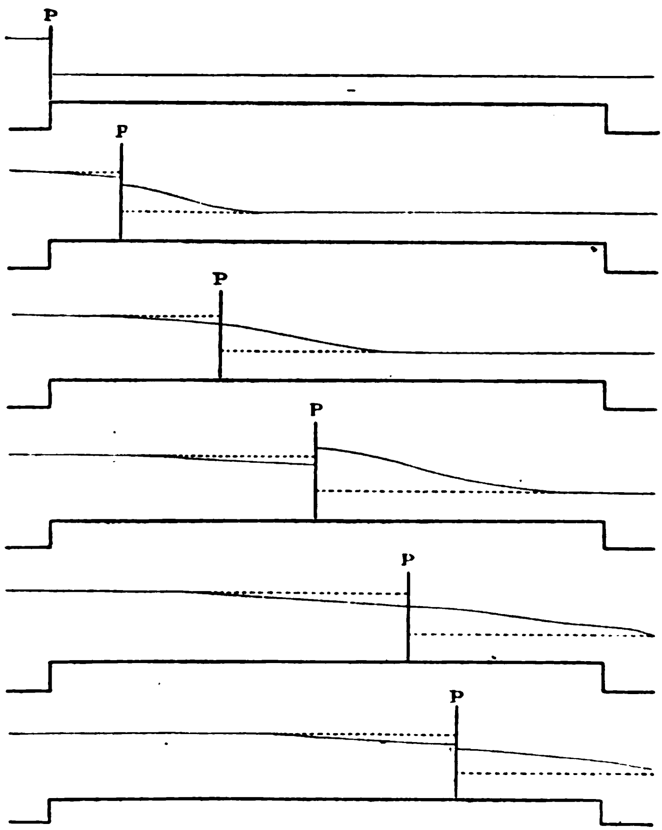


Fig. 33.

experiments. He had marked on the base line the different stations, drawn to scale, at which M. Bontemps' instruments were placed. The velocities of the pistons were also drawn to scale (vertical), and the effect was that in a short distance between the first stations the velocity after rising to a high point—91 feet—rapidly dropped through the middle part of the pipe, going on nearly uniformly, and then increasing at the end. It was all very well to disown the results that M. Bontemps attempted to derive from his experiments; but a reason ought to be given. He had therefore, in another diagram (Figs. 34), attempted to show graphically how air should behave in such a pipe. He had taken water, so as to show by its waves the pressure of the air, and

assumed it to be inclosed in a trough, with a large cistern at each end, one being considerably higher than the other. The piston P, which was supposed to be guided so as to move vertically, was subjected to the pressure of the high cistern, and had on its other side a low pressure. It was immediately sent forward; the wave gathered in front from the displacing of the water in front, while



Figs. 34.

the water behind dropped a little into a hollow, or a negative wave. This went on accelerating the piston until it came to the condition, where the wave piled up in front of the piston was exactly the height of the wave behind it. There was then no further acceleration, but the whole of the water having got a momentum forward, the pressure behind kept on falling a little,

while the pressure in front kept on rising. Then the piston was retarded for some time, until again the wave in front and the wave behind came to a state of uniform motion which continued as long as that state of things lasted. Gradually, as it got to the end of the pipe, the wave had freedom to flow into the larger reservoir, and there was an acceleration, as shown in the diagram of velocities. Thus converting the height of a wave, which was a mere graphic representation, into the pressure of an elastic fluid, there were obtained, as it appeared to him, the various phases of pressure which the air underwent in the pipe, and the various velocities produced in the piston through those variations of pressure, and they appeared exactly to accord with the diagram which resulted from M. Bontemps' experiments. There was another point in M. Bontemps' Paper, about the successive pistons following each other at equal distances, to which he desired to refer. On Fig. 35

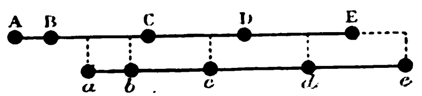


Fig. 35.

he had marked a body to be moved forward with varying velocities through a certain distance, marking the varying velocities by varying lengths of base line; and underneath he had drawn another line in which the same variations of velocity occurred, but at a later period. The distances were all identical. Although the velocities varied at every point, yet as the phases of variation which each body underwent were the same, the distances remained the same, which accorded with M. Bontemps' results. Fig. 36

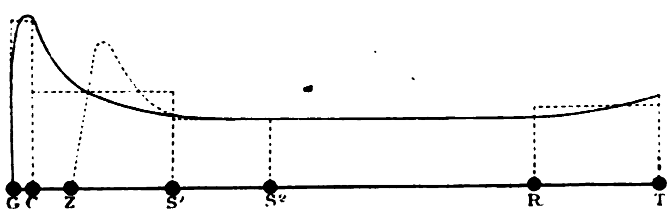


Fig. 36.

indicated exactly what M. Bontemps' experiments showed as to the motion of the two pistons. That of the first piston was represented by a dotted curve running from Z, and then going to the same line as the later piston, shown by the curve beginning at the central station S. Thus, he thought it might be satisfactorily

proved that the air, in the pipe which M. Bontemps had experimented with, behaved precisely as elastic air ought to behave, subject to Mariotte's law, the pressure being proportionate to the density; and there was no reason to suppose that the presence of aqueous vapour, or any other cause, affected the results in such a way as to make the air behave differently.

Mr. H. Eaton said that, as the greater part of the pneumatic tubes in London had been laid under his superintendence, he might give a few facts in connection with the practical working of the system. The extension of the system, on the removal of the central station from Telegraph Street to St. Martin's-le-Grand, involved an additional length of 13¾ miles of new tubes. Of this length more than 1 mile had been laid with 3-inch lead in 4-inch cast-iron pipe, in order to utilise the 3-inch wrought-iron tube laid by Messrs. Siemens. The remainder was 2¼-inch lead in 3-inch iron. The 3-inch lead in 4-inch iron cost about 2*s.* 6*d.* a yard more than the other; but it was laid in 1873, when iron was very dear. The advantage of lead over iron was, he thought, apparent. The lead was protected by cast-iron pipes, which were not so subject to mechanical damage as wrought-iron ones not so protected. The streets of London were often taken up, and he had known several cases where a wrought-iron tube, unprotected by cast iron, had been pierced by a pickaxe. It was a common practice amongst the workmen of gas and water companies to tap a pipe, and, when the contents rushed out, to insert a plug. That might do in the case of gas and water, but in pneumatic tubes it stopped the first carrier that came. Many experiments had been tried to ascertain which was the best and cheapest material for the carriers, and it had been found that those made of gutta-percha, covered with felt, travelled fastest and were by far the best as regarded first cost and maintenance. Carriers in wrought-iron tubes would travel 100 miles before needing repair. The tube from the Central Station to the Stock Exchange was partly lead and partly iron, and there the carriers lasted for a distance of 250 miles. In lead tubes most carriers would run continuously for four months without requiring repair. It had been stated that the maintenance of carriers in the two wrought-iron tubes to the West Strand cost more than that of all the carriers in the rest of the tubes. The whole system of the Electric and International Company was first of lead. The first iron tube was that to the West Strand. Before that no trouble had been experienced from water, although the air was delivered precisely as at present; but in the engine used for the West Strand system water was injected into the pump, and the

pump itself was surrounded by a water jacket: that injection caused water to pass into the tube, so that at two points on the route boxes were inserted to trap the water, and it was necessary to remove it once or twice daily by means of a siphon. It had been suggested that the air should be cooled before being used. But it had been calculated that to cool 2,000 cubic feet of air per minute, corresponding to the quantity passing at present from the pumps, would cost £150 per annum to bring the temperature down from 120° to 70°, supposing the water could always be obtained at a temperature of 50°. Dr. Siemens had stated that the system laid by his firm included the switches, &c. The price quoted by Mr. Preece did not include the valves, but he had made a calculation from which he found that the valves used, divided into the mileage, increased the price from 12*s.* 8*d.* to about 13*s.* per yard. He believed that the carrying capacity of the tubes had not been stated. A 3-inch carrier would hold thirty-six message forms; a 2½-inch carrier would hold fourteen. As business increased so could the carrying power by using forms of thinner paper, or by coupling two or more carriers together. It appeared to him that the radial system as used by the Post Office was best adapted to the purpose for which it was intended. The ideal of perfection in the matter of telegraphs was absolute annihilation of time and space, and the system that made the nearest approach to that appeared to him to be the best. The amount of local traffic between station and station in London was so trifling as not to require the laying of a single tube. All the tubes were used to collect messages from outlying stations to the central station to be transmitted thence by wire, or to convey the messages telegraphed to the central station from the provinces to the nearest point from which they could be delivered by hand. The pneumatic system, as developed by the Post Office, had been utilised in a manner that perhaps might be available for large factories or offices supplied with engine power. The Central Station instrument gallery had an area of 20,000 square feet; the distance from one corner to the other was in some cases 90 yards or 100 yards, and in order to facilitate the transmission of messages rapidly from one part of the gallery to the other he had introduced a very simple system. A message tube was fitted into one side of a box, which was both a forwarding and a receiving box, and connections were made to two cocks, one for pressure and one for vacuum. A boy stood in front of it, and when messages were brought to him he simply inserted them in the carrier, which conveyed them from one part of the room to the other in about

five seconds. There were ten such lines, the longest being 90 yards, and the shortest 60 yards.

Mr. PREECE, in explanation of Dr. Siemens' correction of his statement as to the abandonment of the circuit system in Berlin, said that there were two systems of pipes in Berlin, both of which had been originally worked on Messrs. Siemens' principle. Now only one pipe was worked at a time. The system had not been abandoned in regard to the present working, but it was intended to abandon it in any future extensions. In comparing the circuit system as employed in Paris with the radial system adopted in England, he had no intention of drawing a comparison between the continuous or 'air-rope' system and the mode of working adopted in London. He spoke of the circuit system extended along the streets of a city to meet the requirements of intermediate stations, without reference to the mode of working adopted in the transmission of air.

Mr. CULLEY observed, through the Secretary, that it was not the object of the Authors to show what systems would best apply to conditions totally unlike those which obtained in London; but to describe the system which an experience of many years had proved to be necessary to perform the work to be done at home. The Paper was, in truth, somewhat of an apology for the adoption of the more costly radial system in place of that in use in Paris and elsewhere; and the Authors had endeavoured to show that the latter could not meet the demands of the service, and that the extra expense was unavoidable. Mr. Cowper had stated that, with ten circuits of eight stations each, London would be well served. Mr. Culley felt sure the public would not for a day tolerate the delay to messages which would arise from the substitution of tube circles of eight stations for the existing wire circuits, on all of which the delay on the line was now under five minutes. The Paper referred to telegrams alone, not to the delivery of letters. The messages from the City stations must be brought to the Central Office for transmission into the country within two or three minutes. To accomplish this, the communication, whether by tube or by wire, must, in cases where the traffic was large, be direct. It would be as impracticable to group the Central Station, the Stock Exchange, Leadenhall Street, and Fenchurch Street in one continuous tube as to place London, Liverpool, Manchester, and Birmingham on one wire. As it was desirable to be very definite in the terms employed to denote or describe each different system, he would venture to ask if a mere "up" and "down" line of parallel tubes could be correctly called a "circuit" system? The analogy

of the railway would seem to decide this question in favour of the term "double line." The choice between lead and iron tubes was a point which deserved great consideration. It was not quite fair to compare the cost of Dr. Siemens' 3-inch with the Authors' 2¼-inch tube, and perhaps the best available comparison might be that between the Paris 2½-inch iron tube, and the lead 2¼-inch tube at 13*s.* 8*d.* and 13*s.* 3*d.* respectively. Although it might be said that the circumstances were not exactly alike, yet it was clear that the lead with its iron cover was not much dearer than iron; possibly because in the first case the articles were those in ordinary use, while the particular iron pipe was a special manufacture. But he submitted that nothing less than a large saving would have been a sufficient justification for abandoning the system which had given such excellent results for so many years, and which bade fair to last for an indefinite period, especially when the results obtained in the iron tube were not entirely satisfactory. The rusting of the iron would probably not occur to so great an extent in a tube worked by the engines now employed at the General Post Office. As regarded the suppression of the air reservoir or container, which had been spoken of as an ill-considered measure, he would remark that, in respect to the power of condensing, or rather of collecting, the moisture of the air, the large and very long air-mains employed (each with a capacity of 400 cubic feet), and which were exposed to the air from the bottom to the top of the lofty building, were at least as effective as any other form of container it would have been practicable to employ. However this might be, as a matter of fact, no sensible amount of moisture had ever been found in the lead tubes. No doubt lighter air, or hydrogen, would give better results; but the practical difficulty of employing either, and the cost of hydrogen would seem to be prohibitory. Mr. Cowper had narrated the result of an experiment in which the tube was exhausted before the insertion of the carrier, with a great increase of speed. This was known as the "closed tube" method, and might, in some cases, be used with great advantage. But where the traffic was heavy and continuous, the time gained by the increase of velocity would be lost on account of the interval which must be allowed for exhaustion between each transit. Some allowance must also be made for the extra trouble in working the traffic.

Mr. Sabine, in reply upon the discussion, stated his regret that Mr. Culley had not been present to give some personal explanations, his practical experience being probably greater than that of any engineer in the world in pneumatic matters. With regard to

the discredit which he had been supposed to throw on Dr. Siemens' system, it appeared to him that no one in the course of the discussion had really stated what that system was. Mr. Bramwell had stated that it was not the circular Paris system. Then what was it? Was it the circuit that Dr. Siemens represented as an ellipse, drawn in the form of two straight lines joined by a communication at the end? That could not be, for Dr. Siemens himself disowned the piece at the end, and said that the tubes would work better, or as well, without it. The mere fact of two straight lines being laid together could not form a new system. That had been patented, in 1810, by George Medhurst, who described it in a few plain words: "If there are two tubes of the same dimensions leading from one place to another, packets of letters may be conveyed each way at the same time without the possibility of clashing against each other, and many packets may be conveyed in the same tube, which can never approach each other, but will proceed with a uniform motion and equal rapidity to their destination. Where the tubes enter an air-tight chamber the packets will be deposited, and may be delivered, or forwarded to the next stage through their proper tubes commencing in the same room, and their progress can never be impeded by the seasons or the elements." The up and down line was no more a new system than the London and Brighton railway was a new system. The only thing that the communication at the end did was to connect the two, so that one could do nothing without the other. If a carrier had to be sent from the central to the end station, it would be necessary to expend an equal amount of engine power in drawing a useless amount of air from the end to the central station in the other direction. That part of the invention was not Messrs. Siemens'. The latter in its entirety was much more perfect. It was a system of two concentric circles having air passing through them in opposite directions, so that each station on the line had two methods of arriving at the central station. What had been called Messrs. Siemens' system was only a compromise, which had been adopted perhaps because circumstances did not allow the system to be carried out in its entirety. Dr. Siemens had mentioned that the $2\frac{1}{4}$-inch lead tubes had cost several times as much as iron tubes. That question had been gone into before the present system was adopted, and it was found that if the iron tubes were of the special manufacture required for a pneumatic line, they were as dear as the ordinary articles of manufacture —the lead tube and the cast-iron tube which had been put down previously. Besides, it was perfectly well known, from the working

of the Berlin system, that water was introduced into the tubes. It might be from the pumps, but possibly it was from leakage through the joints. When the tubes were first introduced in Berlin they were supplied at regular intervals with jackets pierced with holes, leading down to wells in the streets, and the water leaking into the wells was periodically pumped out. The behaviour of the tubes in London was similar, but there were no jackets from which to collect the water. With regard to the cost, neither Dr. Siemens nor Mr. Preece were quite accurate. Mr. Preece omitted to state that he had included the valves and other machinery in the 15*s.*; and Dr. Siemens, in stating the price at 8*s.* 4*d.*, forgot to say that neither profit nor superintendence had been included in that sum. The truth probably lay about midway, which would come very near the Paris price of 13*s.* 8*d.*, as compared with 13*s.* 3*d.*, the price of the London lead and iron tubes. The opinion of Dr. Siemens and Professor Unwin, that the expansion of air in a tube was necessarily isothermal, was, he thought, untenable. Experimental facts certainly did not justify that view of the expansion of air in tubes or in any other position. Air set in motion from a container must be set in motion at the cost of some work; and the only work that air could obtain was that which it got from the reduction of the heat in it; and as long as any motion lasted in the air, the temperature could never come back, unless by conduction, to that at which it started. He had conducted the experiments for Messrs. Siemens from the first, when they were made with glass tubes, and afterwards with the actual tubes in Berlin. These, soon after they were laid, had been worked on the continuous system, the air being pumped from one station through the middle station and back again. The loss of heat was so great that on passing over the canal bridge, towards the winter, it would be found that one tube was warm, while the other was covered with ice or snow. In the cellar below the station, one would be found to be quite warm and the other cold. He had recently gone into the central station in London and felt the temperature of the air of the vacuum tubes and of the pressure tubes; and he found what Mr. Wilmot (the practical engineer of pneumatic telegraphs) told him was always the case —that there was not the slightest difficulty in recognising which was the vacuum and which the pressure tube, by the hand, and observing which was warmer and which was colder than the atmosphere. In opening the streets Mr. Wilmot said he could recognise the two tubes in the same way. That did not look like isothermal expansion. If air were inclosed in a confined space,

and expanded, say in a cylinder, and the piston suddenly lifted, the temperature of the air inside the cylinder fell. If air were inclosed in a vessel, and a hole made in the side to let it out, a thermometer held in front would show that the air was chilled in coming out. M. Mignot, a French engineer, had, upon that principle, constructed a beautiful apparatus for producing large blocks of ice. He allowed the air to expand in the passage between the spaces of vessels containing water, which as it passed through it chilled and produced the ice. There was no isothermal effect there. The only difference between M. Mignot's passage spaces and the pneumatic tube was, that while the former were 10 feet long, the latter might be 1,000 feet. In a pneumatic tube of short length there could be no question that the air did not expand isothermally, for it became quickly chilled, and the chilling might be carried to such an extent as to produce ice. If the length were greater the effect produced would be less, because it would be masked by the heat developed by friction and conduction. With regard to the Berlin tube the case was peculiar, for the same air was absolutely pumped round and round the system, and as it passed round became alternately hot and cold. If the system were open at the middle, it might be said that there was some error of observation; but as the same air alternated between hot and cold, it was evident that it did not pass round the system isothermally. He thought it would be time enough to challenge the correctness of the formula when some proof had been put forward to show that expansion in pneumatic tubes was necessarily isothermal. At present it remained simply a matter of speculation, and any error from the unknown rate of expansion was practically eliminated in the formula itself. With regard to vacuum-working, a suggestion had been made based upon a clause in Dr. Siemens' patent specification, that hydrogen would be a valuable substitute for vacuum air. He could scarcely imagine that the suggestion had been made seriously. With every carrier admitted into the tube there would enter atmospheric air, and the hydrogen would soon produce explosive gas, and the lives of the operators would certainly be endangered. There was a very great mistake made in supposing that in practice vacuum-working was much cheaper than pressure-working. As a fact, at the Post Office a 50-HP. engine was used for pressure, and one of the same power for vacuum—both worked up to their maximum; practically, the same number of tubes were used; and no difference had been found in the cost of working. Professor Unwin had discovered a misstatement of the vacuum work with the

steam-engine: that mistake was entirely his (Mr. Sabine's), not Mr. Culley's.

Herr ZELLI, Director of Telegraphs in Vienna, observed, through the Secretary, that the aim of the system had been to forward telegrams arriving at the central station to the addressees in the several districts, to forward from the district offices those intended for country addressees to the central office, and to transmit letters from one district to the others, all with the utmost possible despatch. The letters were not restricted in number of words, but their weight must not exceed 10 grammes. They might be open or closed, but must be handed in without being fastened by sealing-wax.

For carrying out this design there were ten stations, connected by a line of tube, which at both ends entered into an apparatus serving for the reception and the despatch of telegrams and letters. The various stations were:—Central Telegraph Station, No. 1; Meat Market, No. 2; "Kärnthnerring," No. 3; "Wieden," No. 4; "Gumpendorf," No. 5; "Neubau," No. 6; "Josephstadt," No. 7; "Exchange," No. 8; "Leopoldstadt," No. 9; and "Landstrasse," No. 10. The stations Nos. 1 to 7 were in a circular closed line, so connected that No. 1 formed the commencement and end of the line, while the remaining three stations were branches from this closed circuit.

Compression and rarefaction of the air were accomplished by eight air-pumps, of which four served for compression and four for rarefaction. The former had a diameter of 450 millimètres and a height of 860 millimètres, so that each had a capacity of 0·136 cubic mètre, and they made forty to fifty strokes per minute. The same number of strokes per minute was also made by the latter; but these had a diameter of only 350 millimètres, a height of 660 millimètres, and a capacity of 0·063 cubic mètre.

For working the air-pumps, two horizontal steam-engines without condensers, but with variable expansion gear which could be regulated at will, were used as follows in stations 1 and 5, the first with 20 lbs., the last with only 11 lbs. pressure. In the same stations were kept, as reserves, two extra steam-engines of similar make, so that during the occasional repairs of the whole machine, the working might still proceed.

There were twelve reservoirs of strong iron plate, of equal capacity with the whole pneumatic tube system, six of which were for compression, with a capacity of 116 cubic mètres, and six were vacuum reservoirs, with a capacity of 90 cubic mètres. Two reservoirs for compressed air, and two reservoirs for vacuum, were

placed at each of the stations 1, 2, and 5. These reservoirs were connected with the air-pumps and the pneumatic apparatus of the station in which they were situated.

A manometer was used, each degree of which showed the pressure equal to the weight of 1 centimètre of quicksilver.

Each station was fitted with a commencing, an intermediate, and a terminal apparatus.

In general, the pneumatic apparatus consisted of a conical tube with a small locking cover to introduce the carrier with the telegrams and letters, of a large locking cover to receive the carrier arriving with letters and telegrams, and of a tube-closing valve interposed between the small and large locking covers in a cylindrical box, which served either to open or to close communication with the tube.

Besides the above-mentioned constituent parts, the pneumatic apparatus possessed those described in the following category:—

In the commencing apparatus, a regulating valve fixed at the back, and used for connecting the apparatus with the reservoir tube; for connecting the apparatus with the discharge air-tube or free atmospheric air; and for shutting off both these connections. And a forwarding valve inserted in the discharge tubes of both sorts of reservoirs in the station and in the tubes coming from the regulating valve of the pneumatic apparatus, and so arranged that the apparatus and the line-tube could be connected either with the compression or vacuum reservoir, or with both kinds of reservoirs shut off.

In the intermediate apparatus, which was not in direct communication with the air reservoirs, and could therefore be only put in connection with them by the tube, and was provided with an air-outlet tube instead of the regulating valve; a valve-lid on the end of the pneumatic apparatus, which could, by a lever, be either opened to establish communication with the outer air, or shut to keep up through communication. Each station provided with this sort of apparatus was connected with at least two line-tubes, the ends of which led into the apparatus. Between both parallel entering line-tubes was a large connecting valve, and before this in each separate line, a locking contrivance was inserted, fitted with a light hand-lever. The large connecting valve served to put in communication the line-tubes discharging into the station without interruping the passage of air through the apparatus. The vacuum locks prevented the escape of the compressed or rarefied air from the tube when the apparatus was opened. By the admission of air by a small lifting valve, the train

going out of the station could be brought up behind the large connecting valve.

The terminal apparatus possessed the same constituent parts as the intermediate apparatus, but had only one light vacuum lock. Each pneumatic apparatus was also fitted with a manometer, and all were firmly set up on strong iron tables.

Twenty pieces of pneumatic apparatus were introduced in the pneumatic system in Vienna, viz.:—Nine pieces in three stations at the commencement of the line; eight pieces in four stations in the central portion of the tube; and three pieces in three stations at the end of the line.

The air reservoirs in stations 1, 2, and 5 were brought on one side into connection with the air-pumps worked by the steam-engines, and on the other side with the commencing apparatus by its own tube. The length of this connecting tube was 2,457·8 mètres, of which 251·8 mètres were of cast iron, with an internal diameter of 105·4 millimètres, or 2·18 cubic mètres capacity, and 2,206 mètres of rolled iron, with an internal diameter of 6·5 millimètres, or 7·26 cubic mètres capacity.

The tube connected the pneumatic stations, and formed the actual channel through which the telegrams and letters were forwarded.

The length of the tubes was 11,852·45 mètres. The single lengths of tube, made of rolled iron, were 5 mètres long and 65 millimètres in diameter, and had an internal capacity of 38·81 cubic mètres each.

According to the position and purpose of the several stations, they came under three categories:—

1. Head, or chief stations, in which pneumatic commencement apparatus and air reservoirs were placed. (Stations 1, 2, and 5.)

2. Intermediate stations, where two or more tubes entered, and so had two or more pieces of intermediate apparatus. (Stations, 3, 4, 6, and 7.)

3. And terminal stations, where one or more ends of the tubes entered, supplied with terminal apparatus. (Stations 8, 9, and 10.)

To the appliances for working belonged:

(*a*) Telegram boxes, for the reception of the telegrams and letters, of hammered steel, 50 millimètres in width and 110 millimètres in length, over which a leather cover was slipped, to prevent the contents of the box from falling out during its passage.

(*b*) Piston boxes, similar to the last, but with a leather ring near one end, which fitted hermetically to the inner surface of the

tube. The piston boxes served to drive the telegram boxes, chiefly by the hermetical closing of the tube, and so preventing the loss of too much air near the telegram boxes, between which and the tube there was a play of 14 millimètres. Numbers were put on the telegram boxes corresponding to the numbers of the stations.

Two neighbouring pneumatic stations were also connected by a telegraph wire, and supplied with the necessary electric apparatus. The telegraphic correspondence was confined to the necessary advice and signalling of the departure or arrival of a carrier, or the required supply of air. The telegrams and letters, if the addressee did not live within the delivering radius of the station to which the message was directed, were forwarded to the pneumatic station concerned for delivery, and were sent by the pneumatic train in the telegram box marked with the number of the station in question. In each pneumatic station messengers were in readiness to deliver the telegrams or letters. There were also five branch offices, appointed for the reception of telegrams and letters, to be collected for forwarding from the pneumatic station.

The forwarding of the carriers was arranged according to their several orders of handing in.

Through the stations 1, 2, 3, 4, 5, 6, and 7, back to station 1, a train of six telegram boxes and one piston box was in constant circulation, and was stopped in turn at each station, and the arriving letters and telegrams destined for that station were taken out, and others despatched.

The manipulator in No. 1, from which the train of carriers started, filled the boxes with the telegrams and letters waiting to be forwarded to their respective stations. He then telegraphed to the next station, and put the boxes in the small locking cover of the apparatus in the connecting stations 1 and 2. He next, by means of the cock at the other end of the apparatus, opened communication with the compressed-air chamber, and the air acting upon the piston box, introduced last of all, the boxes were forced to station 2. The atmospheric air in the tube was thus driven out through the apparatus in station 2.

By the noise produced by the movement of the carriers in the tube, the manipulator at station 2 heard when the train of carriers was near; he partially stopped the free exit of the escaping air, and thus the train was checked, and only proceeded at a slow rate into the apparatus.

As soon as the train had arrived, he advised the operator at station 1, who on his part immediately shut off the entrance of the compressed air. The manipulator in No. 2 opened the large closing

cover of the apparatus there, and removed the boxes destined for station 2, emptied them of their contents, and forwarded in a similar manner the collection of letters and telegrams to station 3. When the train had arrived there, the manipulator at station 3 shut off the apparatus from the tube which was now filled with compressed air, and drew the train forward into the closing cover of the apparatus, exchanged the outgoing for the incoming telegrams, telegraphed to station 4, and put the train into the tube leading there. Station 3 would then, by means of the lifting valve, put the two tubes, 2 to 3 and 3 to 4, in communication, and thus the compressed air out of the reservoir of station 2 by tube 2 to 3 passed into tube 3 to 4, and forced the train up to station 4. On the train arriving there, the manipulator at station 2 shut off the compressed air, station 4 called station 5, and laid the train leading to station 5. The official there now exhausted the air out of the main tube, and thus drew the train from station 4 to his own, which the manipulator effected by connecting the apparatus with the reservoir of rarefied air (vacuum reservoir).

From station 5 to 6, and from that to 7, the train was again driven by the compressed air of the reservoir of station 5, and, finally, from station 7 to station 1, whence it started, the manipulation being a repetition of that from station 2 to 5.

In the direct lines, as stations 1 and 8, 2 and 9, and 2 and 10, the manipulation was similar to what had been described, namely, the train was pushed out by compressed air and drawn back by rarefaction.

Each station, as a rule, was provided with only one box; still, in case of necessity, two boxes could be forwarded from the same station, though the number of boxes by one train must never exceed eight at the most.

By the application of different kinds of cocks, valves, slides, &c., precautions were taken, in the event of interruptions in the working between the several stations, to render it possible to carry on the working otherwise than as described. The length of the line extending from No. 1 through 7 back to 1 was 8,832 mètres, and the train occupied fifteen minutes in transit, of which seven minutes were taken up with the stoppages at the stations and eight minutes for the actual passage of the train. In the event of any interruption in the tube, the place was ascertained by a simple instrument connected with a chronograph, within 0·02 per cent. of the length of the tube, in the longest line in Vienna within 1 mètre. In order to increase the traffic in the local correspondence of Vienna, negotiations were in progress for lowering the present

tariff of 20 kreuzers to 10 kreuzers for letters, and to 6 kreuzers for express correspondence cards.

RETURN of the ROYAL PNEUMATIC STATIONS from the 1st of May, 1875, to the 30th of November, 1875.

Stations.	Letters sent out.	Telegrams forwarded to the Central Station.	Telegrams.				Remarks.
			Coming into Central Station.	Forwarded thence.	Delivered locally.	Total.	
I. .	636	176,083	643,836	..	308,278	..	The stations were opened for pneumatic working on the 1st of May, 1875.
II. .	908	29,981	..	54,819	..	..	
III. .	741	51,099	..	80,165	..	..	
IV. .	358	6,514	..	29,981	..	..	
V. .	745	1,442	..	16,198	..	..	
VI. .	297	4,184	..	19,783	..	..	
VII. .	210	2,560	..	11,087	..	..	
VIII. .	168	35,783	..	26,525	..	..	
IX. .	322	9,567	..	82,504	..	..	
X. .	277	4,357	..	14,496	..	..	
Total	4,662	321,570	643,836	335,558	308,278	643,836	

Dr. STEPHAN observed, through the Secretary, that in Berlin there were at the present time two pneumatic systems, which had been laid down at different periods. The older connected the Chief Telegraph Station with the Exchange Station; the other system was used for transmitting telegrams between the Chief Station and the stations at the Brandenburg Gate and the Potsdam Gate. The distance between them was as follows:—

	Mètres.	Yards.
I. From the Chief Telegraph Bureau to the Exchange	890	973·33
II. " " " " Brandenburger Gate	1,442	1,577
III. " Brandenburger to Potsdamer Gate	831	908·8

The first system had been fully described[1] in a Paper by Dr. Brix on "The Pneumatic Despatch Tube between the Central Telegraph Station and the Exchange Building in Berlin," of which paper the following was an abstract:—

As the success of forwarding messages by pneumatic despatch depends upon a knowledge of the laws of motion of air in tubes, it is advisable to investigate first the principle of this system of transmission, under the limitations necessary in employing tubes of comparatively small diameter and with low working pressure. With a view to establish these principles, the following experiments were made with tubes of various diameters and lengths. By means of a pump with fly-wheel and winch, which could be used either as vacuum or pressure

[1] *Vide* "Zeitschrift des Deutsch-Oesterreichischen Telegraphen-Vereins." Jahrgang xiii. (1866), p. 90, &c.

pump, or as both pressure and exhaust pump, the air was condensed or rarefied in a reservoir. The reservoir communicated with the atmosphere by means of the tube, in which was measured the velocity of the air. The pressure in the reservoir was measured by a mercurial manometer. The quantity of air passing was measured by a gasometric arrangement. The measured quantity of air, divided by the section of the tube, gave the velocity. By Mariotte's law the velocity at opposite ends of the conducting tube can be readily calculated. Suppose, for instance, the air in the reservoir diminished to and maintained at half atmospheric pressure, and the velocity of the air of atmospheric tension entering the tube to be 50 feet, then the quantity of air leaving the reservoir being double the volume, the velocity must be 100 feet.

Let v_1 be the final velocity of the air in the tube; v_{11} the initial velocity, and v the velocity at a point distant x from the beginning of the tube; the mean velocity will be $v^1 = \frac{v_1 + v_{11}}{2}$. Let l be the length of the tube, and d the diameter (both in feet), h the pressure of the entering air, h_1 the pressure of the issuing air, $h - h_1$ the effective pressure, α a constant: then—

I. The final velocity,

$$v_1 = \alpha \cdot \frac{h - h_1}{h} \cdot \sqrt{\frac{d}{l}};$$

II. The initial velocity,

$$v_{11} = \alpha \cdot h \cdot \frac{(h - h_1)}{h^2} \cdot \sqrt{\frac{d}{l}};$$

III. The velocity at the point x,

$$v = \alpha \cdot \frac{(l - x) h_1 + x h}{l} \cdot \frac{h - h_1}{h^2} \cdot \sqrt{\frac{d}{l}};$$

IV. The mean velocity,

$$v^1 = \alpha \cdot \frac{h^2 - h_1^2}{2h^2} \cdot \sqrt{\frac{d}{l}}.$$

These formulæ are only approximative. The constant α is dependent on the inner surface of the tube, but was experimentally shown to be 15,950. Required, for instance, the mean velocity of the air in a tube of 13,000-feet length, and 3 inches diameter, for a pressure difference of 1 atmosphere, there is obtained:—

(1). At 1 atmosphere pressure (in excess),
$h = 2$ atms., $h_1 = 1$ atm.,
a mean velocity of 26·2 feet per second;

(2). At 1 atmosphere under pressure (vacuum),
$h = 1$ atm., $h_1 = 0$ atm.,
a mean velocity of 35 feet per second.

(3). At $\frac{1}{2}$ atmosphere pressure and $\frac{1}{2}$ atmosphere vacuum $h = 1\frac{1}{2}$ atm., $h_1 = \frac{1}{2}$ atm., a mean velocity of 31·1 feet per second.

The small moment of inertia of the mass of the reservoir, and the momentum of the air itself, disappear in comparison, as quantities, with the friction of the air in the tube. By the circuit system important advantages are gained. As appears from formula IV., the mean velocity of the air depends upon the factor $\frac{h^2 - h_1^2}{h^2}$, which remains unchanged when h and h_1, and also their difference, are proportionally diminished. The work expended in the pump is directly

proportional to the density of the compressed air, which is carried off proportionally as h_1 increases. As by the circuit system the mean density in the tube can be reduced, so can also reduction be made in the power expended. The following short tables of experimental results show close agreement between the calculated and observed quantities, and serve to indicate how nearly the preceding formulæ are correct.

RELATION BETWEEN FINAL VELOCITY AND PRESSURE.

At one end super-pressure, at the other atmospheric pressure.

$h - h_1$ in Centimètres.	$\frac{h - h_1}{h}$	Quantity in Cubic Feet.	Velocity, in Feet per Second. Observed.	Calculated.
16	0·174	0·47	22·6	22·0
18	0·192	0·51	24·6	24·3
20	0·208	0·55	26·6	26·2
22	0·225	0·59	28·6	28·4
24	0·240	0·64	30·5	30·2
26	0·255	0·67	32·2	32·1
28	0·270	0·71	34·0	34·0

The pressure was measured by a mercurial manometer, the quantity of air by a gas-meter; the length of the experimental tube was 348 (Prussian) feet, and the diameter ½ inch. The barometer stood at 760 millimètres during the experiments.

RELATION OF VELOCITY TO PRESSURE.

At one end super-pressure, at the other vacuum.

Pressure in Centimètres.	Quantity of Air-Current, in Cubic Feet. In Middle.	At End.	Calculated.
± 7	0·186	0·205	0·201
± 10	0·240	0·277	0·270
± 12	0·267	0·317	0·311
± 16	0·313	0·396	0·396

RELATION OF VELOCITY TO LENGTH OF TUBE.

$h - h_1$ in Inches.	Diameter in Inches.	Length in Feet.	Quantity in Cubic Feet.	Velocity, in Feet per Second. Observed.	Calculated.
6	0·25	112	0·7	34·3	34·3
—	—	84	0·8	39·2	39·6
—	—	56	1·0	49·0	48·7
—	—	28	1·4	68·6	68·6

The calculated values are based on the assumption that the velocity varies inversely as the square root of the length.

RELATION OF VELOCITY TO LENGTH OF TUBE.

$h - h_1$ in Inches.	Length in Feet.	Diameter in Inches.	Quantity in Cubic Feet.	Velocity, in Feet per Second. Observed.	Calculated.
12	100	6·75	0·860	42·1	42·1
—	—	5·20	0·450	36·4	36·9
—	—	3·25	0·185	27·0	26·0
10	—	6·75	0·810	39·6	39·6
—	—	5·20	0·401	32·2	34·6
—	—	3·25	0·161	23·4	24·4

These calculated values are based upon the law that the velocity varies as the square root of the diameter of the tube.

The following table gives the mean velocities of the air in tubes of 13,000 feet in length, with various diameters, and with the application of

(*a*) 1 atmosphere sur-pressure;
(*b*) 1 atmosphere under-pressure;
(*c*) ½ atmosphere sur- and ½ atmosphere under-pressure, as follows:—

Diameter in Inches.	Mean Velocity.		
	1 Atmosphere Sur-pressure.	1 Atmosphere Under-pressure.	½ Atm. Sur-pressure. ½ Atm. Under-pressure.
2½	23·9	32·0	28·4
3	26·2	35·0	31·1
3½	28·3	37·8	33·6
2	30·3	40·4	35·9

The scheme of the line of pneumatic tubes is as follows:—Two parallel tubes of wrought iron, 2½ inches in diameter, are laid under the pavement at a depth of 3 feet. These tubes are connected about 1 foot from the end by a cross tube in the Exchange building; the parallel tubes terminate with cocks or stop-valves. In the Telegraph Station one of the tubes, about 5 feet from the end, communicates through a cock with a reservoir of compressed air; the other tube at 1 foot from the end is also in connection through a cock, with the reservoir of air at reduced pressure. A continuous stream of air is maintained in the tubes by an air-pump.

The carriers (*Depeschenwagen*) consist of a central despatch-carrying compartment, provided at each end with two wheels, the planes of revolution of which are at right angles, so arranged that a line passing along the centre or axis of the carrier would also pass along the diameter of each of the four wheels. The wheels or runners are massive, and of hard steel, running on polished axles. The despatch chamber is of brass tube 7⅜ inches long, 1⅜ inch outer diameter, and $\frac{1}{32}$ inch thick. It is closed with two iron caps, which carry projecting pieces for the axles of the runners. The runners are about 1½ millimètre less in diameter than the tube.

The end of one tube serves as a departure station; the end of the other as an arrival station. On the departure tube are two cocks; that near the receiving station being closed, the cock near the end is opened and the carrier introduced. The terminal cock is then closed and the other opened, when (the tube being inclined downwards) the carrier rolls into the main tube. The other tube at each station has a receiving chamber, with proper apparatus to catch the carrier. Both stations are underground. At one portion of the line the tubes pass over an iron bridge, rising from the level by a mean gradient of 1 in 6, and falling to the level on the other side of the bridge. The bridge is a swing-bridge over a river, and the tubes have to be thus raised to admit of ships passing under them at high tides. There are four difficult bends in the course, two being of 40-feet radius.

The total length of the two tubes between these stations is 2,835 feet, and with 9-inches mercury pressure and vacuum the passage is accomplished in ninety-five seconds to the Exchange, and in seventy seconds from the Exchange. The foregoing formulæ of Dr. Siemens' show a calculated mean velocity of 95·69. About eight hundred despatches a day have been forwarded through the tubes.

The subsequent system differed from the first only in the following particulars :—

1. The internal diameter of the pipes was 3 English inches.

2. The apparatus for despatching and receiving had been altered and made into one.

The mode of working in both pipe-systems was the same, and had not been altered since described in the before-named "Zeitschrift."

The results of the works laid down by Messrs. Siemens and Halske, of Berlin, on the principles worked out by Dr. Siemens, had been entirely satisfactory.

In the extension of the present pneumatic system about to be undertaken, the principle upon which that system had been worked could be abandoned, inasmuch as the traffic between the telegraph station intended to be connected with the existing network would not be so considerable as to warrant the additional and higher working expenses which would be incurred if the permanent air-current were retained. For the present conditions, on the contrary, it seemed perfectly sufficient to allow the despatch of telegrams between the individual stations to take place at fixed intervals of time—every fifteen minutes—as with the pneumatic systems in Paris, and lately in Vienna. In the time in which no despatch took place, the work done by the engine—compression or exhaustion of the air required for the sending of messages—could be stored up in air-reservoirs of greater dimensions.

Thus the entire work of the engine was utilised, and the working expenses would be lower, than with the system of permanent air-circulation in the pipes. The latter system, indeed, had the great advantage, in the case of a very brisk traffic, of enabling telegrams to be sent at any moment; but, as stated above, such was not the case in Berlin. On this account alone, Siemens' system would not be retained in the new pneumatic network.

In the extension about to be undertaken, altogether fifteen telegraph stations would be connected with each other (Fig. 38). The aggregate length of pipes necessary for this amounted to 20,000 mètres (12 miles 752 yards), and their breadth would be 65 millimètres (2·559 inches). The air employed as propeller would be compressed or exhausted in large reservoirs by four engines, to be erected at different points of the system. The reservoirs for compressed air would only be connected with the pipes when a despatch of telegrams was about to take place; whereas the reservoirs for rarefied air would be permanently connected with the pipes. These pipes would be open only during the despatch of the carriers. In order to lessen as much as possible the time of despatch, the net-

work had been so planned that the telegraph bureaux, as indicated in the sketch below, were divided into two circuits, each with two engines. Both circuits were connected with the Chief Telegraph Bureau, numbered 1. As the two ends of one current, which met in the chief office, had been also connected with the office in the Exchange, numbered 9 in the sketch, it was possible to carry on the traffic taking place between these two offices during Exchange time without delay, by sending out carriers every five minutes.

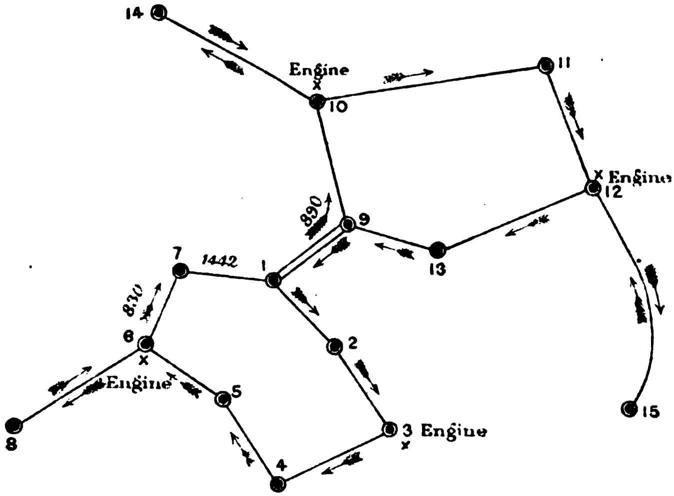


Fig. 38.

The three offices really situated outside the pipe circuit (Nos. 8, 14 and 15) would be connected with the nearest office by branch pipes.

In the closed circuits the transmission of telegrams always took place in the same direction, and therefore either through compressed air only, or through exhausted air only. In the branch pipes, however, the service would be conducted in both directions; in one by using compressed air, and in the other by exhausting the pipes of air.

November 30, 1875.

THOS. E. HARRISON, President,
in the Chair.

The discussion upon the Papers, No. 1,439, "The Pneumatic Transmission of Telegrams," by Messrs. Culley and Sabine, and No. 1,445, "Experiments on the Movement of Air in Pneumatic Tubes," by M. Bontemps, occupied the whole evening.

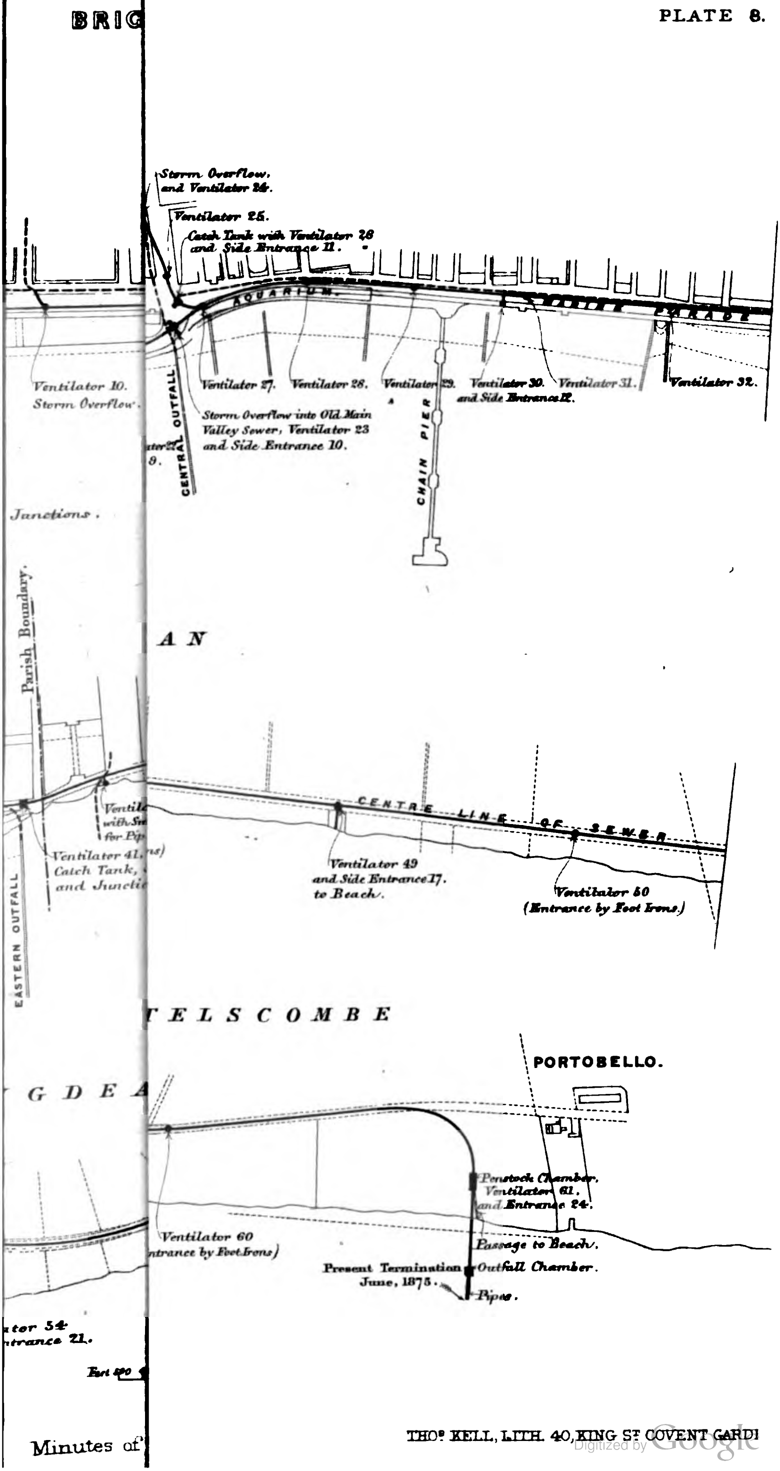
December 7, 1875.

THOS. E. HARRISON, President, in the Chair.

THE following Candidates were balloted for and duly elected WALTER BUTLER, ANDREW JOHNSTON, JOHN KENNEDY, CHA BENJAMIN LE MESURIER, WILLIAM ROBINSON, JAMES WILLIAM DALL, WILLIAM STEVENS, EDWARD GRAY STRONG, GEORGE TU WALCH, and JOHN SMITH WHITLOCK, as Members; Major C ADOLF ADELSKÖLD, FREDERICK HENRY ANSON, WILFRED BA EDWARD FISHER BAMBER, JOSEPH BRADY, BENJAMIN JOHN B BRUCE, JOHN BRUNLEES, Stud. Inst. C.E., PHILIP BULMER, RIC CAIL, WILLIAM THOMAS HENRY CARRINGTON, JOSHUA CARTWR JOHN COATES, Lieut. AUGUSTUS SAMUEL WILLIAM CONNOR, B CHARLES CURREY, JAMES HENRY DAWSON, THOMAS INGLIS D WILLIAM JAMES DOHERTY, JOHN DONALDSON, GEORGE SELWYN WARDS, Stud. Inst. C.E., HENRY OAKDEN FISHER, ALAN GR DALTON, Stud. Inst. C.E., FREDERICK GRIFFITH, ROBERT CARR HA ROBERT CADDING HEMBEROW, HENRY ELLIS HILL, WALTER G IZARD, Lieut. WILLIAM HENRY JOHNSTONE, R.E., Lieut. BARBER LINDSELL, R.E., HUGH LEWIN MONK, ALEXANDER MU THOMAS JOHN FRANCIS NICOLLS, B.A., THOMAS FRANCIS O'M RICHARD QUIGLY, Lieut. WILLIAM HANS RATHBORNE, R.E., PLA REYNOLDS, WILLIAM HANBURY PETTINGAL SHERMAN, ERNEST A SIBOLD, WILLIAM KITSON STENT, Stud. Inst. C.E., ALEXA DAVIDSON STEVENSON, Stud. Inst. C.E., HOUSTON STEWART STE JOHN TATE, ROBERT H. THURSTON, M.A., NANAJI NAR VASALEKAR, ZACCHEUS WALKER, Jun., Stud. Inst. C.E., STE WATKINS, THOMAS EDWARD WEST, Stud. Inst. C.E., ARTHUR WILSON, ROBERT WILSON, and GEORGE BACKHOUSE WITTS, as Associates.

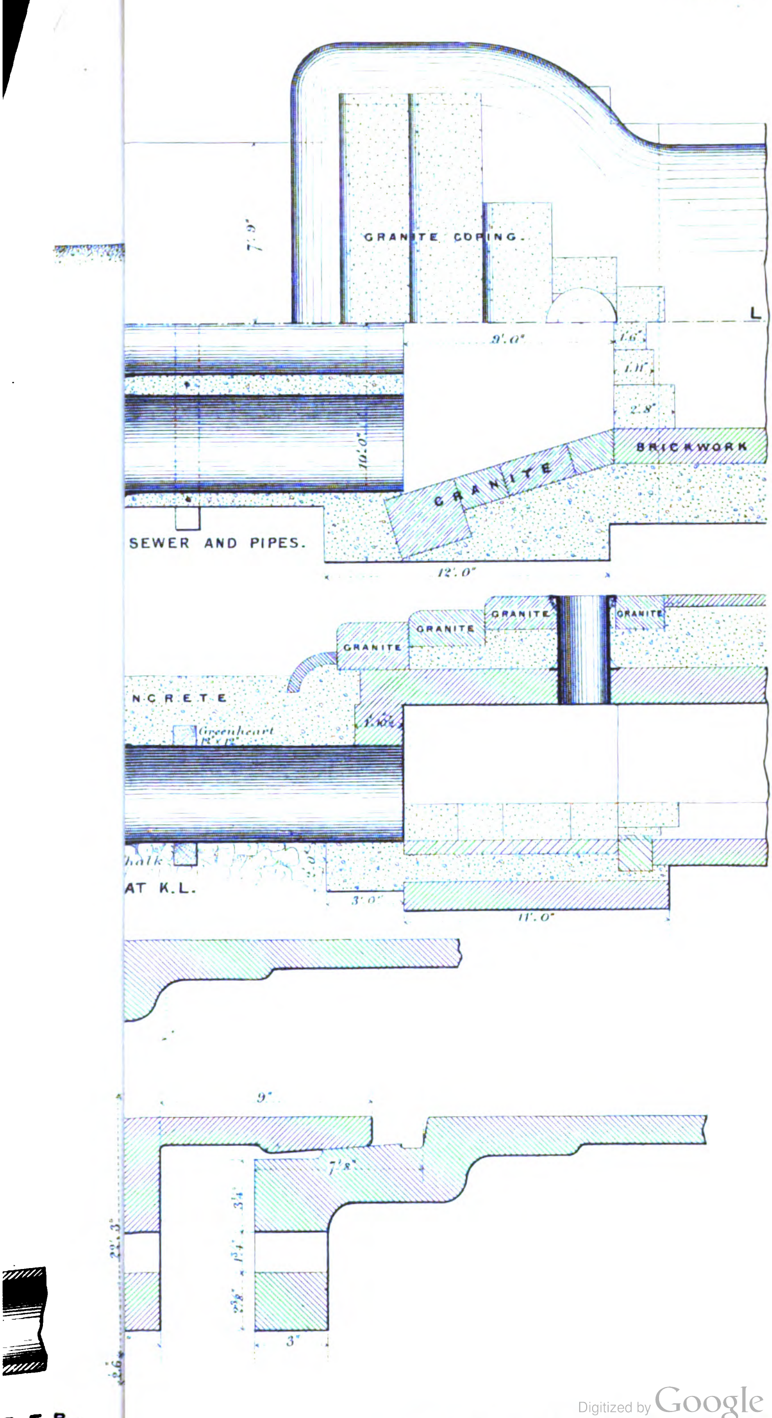
It was announced that the Council, acting under the provi of Sect. III. Cl. VIII. of the Bye-Laws, had transferred J KIMBER from the class of Associate to that of Member.

Also that, under the provisions of Sect. IV. of the Bye-L the following Candidates, having been duly recommended,



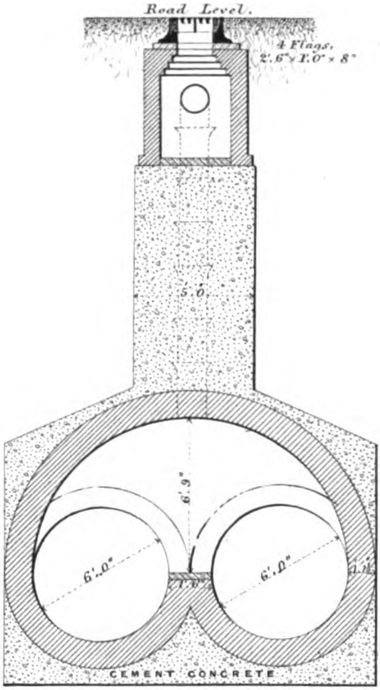
Minutes of

THO^S KELL, LITH. 40, KING S^T COVENT GARD



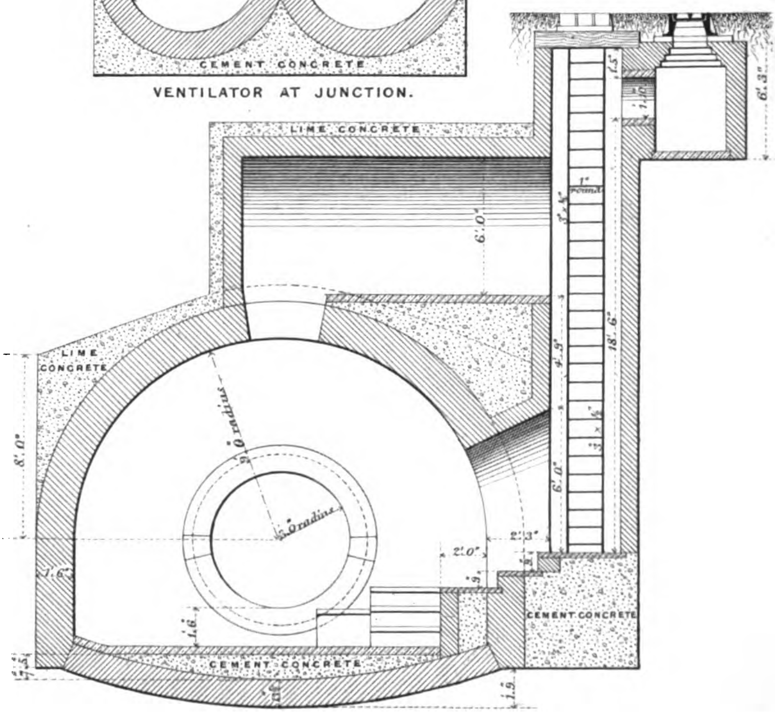
THOS KELL, LITH. 40, KING ST COVENT GARDEN

Fig: 9.



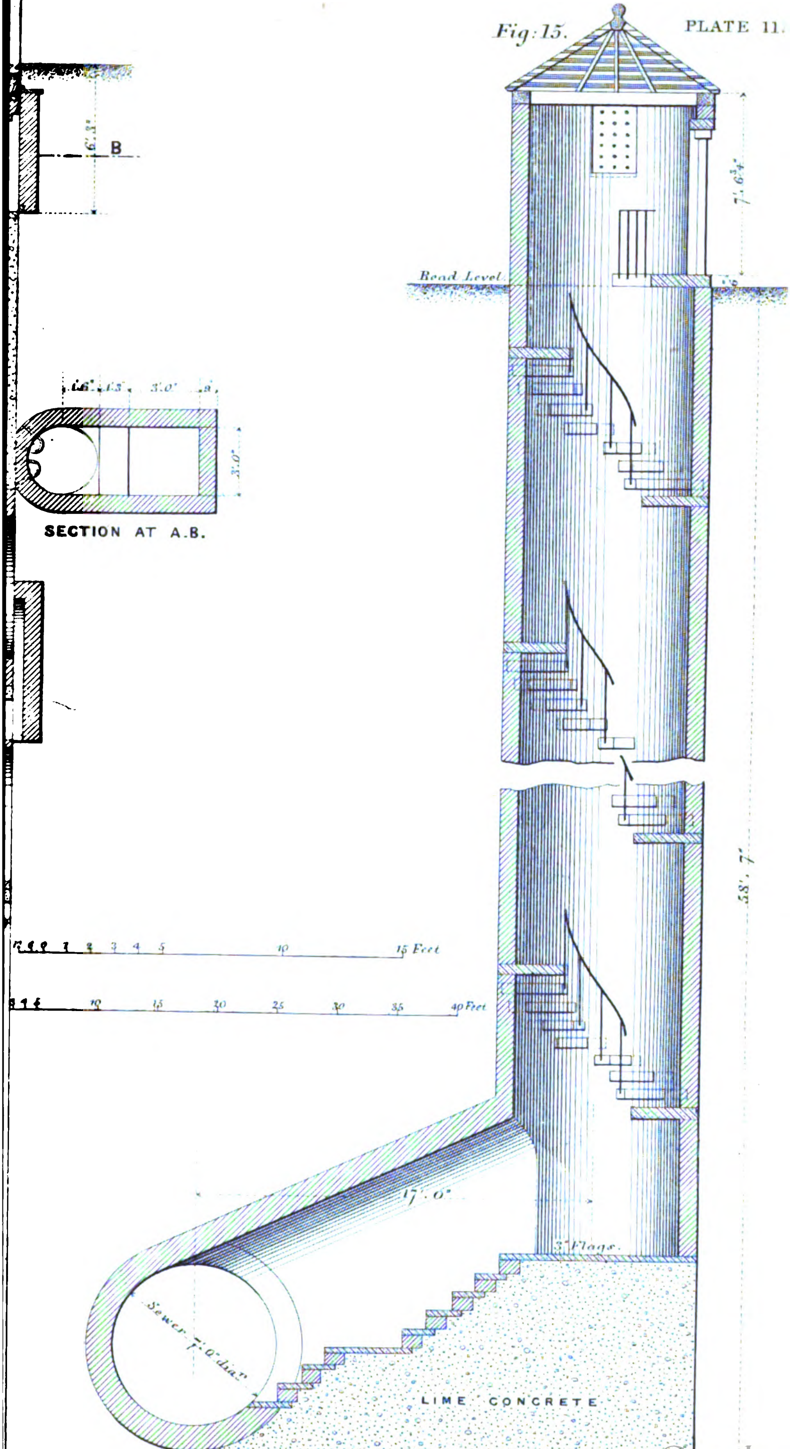
VENTILATOR AT JUNCTION.

Fig: 8.



CATCH TANK, MAIN VALLEY JUNCTION AT STEYNE.

Fig: 15.



AD.

SIDE ENTRANCE WITH VENTILATING HUT.

been admitted as Students of the Institution:—Thomas Burrell Bewick, Henry George Boyce, Horace Boardman Cox, Francis Wolley Dod, Edmund Colvile Elliot, Edward Henry Elton, Robert Abraham English, Charles Firth, Henry Hoyne Fox, Ernest Gordon Fraser, Joseph Gabbett, Justiniano Aurelio Galvez, Duncan George, Alfred George Harrison, Hamilton Theodore Harwood, Arthur James Haslam, Saint John Hewitt, Arthur Hicks, Arthur Edward Hight, William Hodgson, Arnold Horne, George Buchanan Lambert, Oswald Campbell Lees, John Bonfoy Leventhorpe, John List, Charles James M'Connell, Alexander MacGregor, Charles Algernon Moreing, George Streatfeild Morley, Joseph Richard Clinton Nicolls, George Leonard Parrott, Owen Parry, Ebenezer Pentelow, Francis John Pope, Richard John Gifford Read, Arthur Bennett Richardson, Reuben William Roberts, Charles Lawrence Pemberton Robinson, John Newman Robinson, George Pringle Rose, Charles Brooke St. John, Luke George Scouta, Sam Shaw, Fred Simpson, Kent Hume Stephen, George Henry Stephens, Alfred Weeks Szlumper, Arthur Ventris, Edward Walter Vowell, William Valon Watson, George Whitehouse, William Wilson, and Barclay Hughes Young.

No. 1,449.—"The Brighton Intercepting and Outfall Sewers."[1]

By John George Gamble, B.A., Assoc. Inst. C.E.

I.—Local Description.

The area affected by these works is nearly coincident with the parliamentary borough, and comprises the whole of what is ordinarily called Brighton, viz., the districts united under the authority of the Hove Commissioners, as well as the municipality of Brighton. Portions also of the parish of Rottingdean are, or may be, drained into the intercepting sewer. According as the old cesspools are abolished, or tributary sewers are constructed in the outskirts, this area will increase; at present it is about 1,800 acres. The rateable value, according to the estimate for the year 1874–5, is £556,500, of which the sum of £446,600 is assigned to Brighton, and £109,900 to Hove. The average rates in Brighton for the last few years have been *5s. 2d.* in the pound.

[1] The discussion upon this Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

The population of the parliamentary borough in the middle of 1874 was estimated at 109,319.

The range of tide is about 15 feet; the greatest rise being 22 feet, the spring rise 20 feet, and the least 9 feet.

The east, north, and high-lying portions of Brighton are built on the 'upper chalk,' or 'chalk with flints.' Chalk indeed underlies the whole of the borough, but westward, and in the valleys, there is a considerable thickness of overlying strata. A stratum of fine sand generally rests on the chalk, and is followed by layers of water-worn boulders or crushed flints; the former being chiefly observed at the east end, the latter at the west end of the town. Above the sand and boulders is the 'coombe rock,' consisting mainly of chalky debris of a yellowish brown colour. A stratum of clay is found near the surface at the west end of Brighton.

II.—Previous Drainage and Schemes.

Until about thirty years ago, the sewage and household water was drained into cesspools. Such sewers as there were chiefly served to convey away rain-water: these discharged directly on to the upper part of the beach, and were no great nuisance. When, however, the houses were drained into the sewers, the sewers became a great nuisance, and were in most cases lengthened, being gradually extended farther and farther seaward. In 1870 an Act was obtained for the construction of the works, and as the area affected was not all under the Brighton Town Council, a Board was formed to carry out and maintain the sewer. When that Act was passed, there were eight outfalls. (Plate 8.) Taking them in order from west to east, they were as follows:—

St. Aubyn's Villas sewer.
Sussex Road „
West Hove outfall „
East Hove (Brunswick Square district) sewer.
Western Brighton outfall „
Central „ „ „
Eastern „ „ „
Rifle Butts Road sewer.

Two of these were abandoned during the progress of the works; and, with the exception of the Sussex Road sewer, all are now abolished, the sewage passing to the outfall at Portobello.

It cannot be denied that in 1870 four of these outfalls—viz.,

three at Brighton and one at West Hove, were very efficient; they carried the sewage a long way beyond low-water mark, and little was seen from the shore except discoloured patches on the surface of the sea when it was calm. The inhabitants were not, however, content with these outfalls; they consulted different Engineers, and got various advice. Mr. Hawksley, Past-President Inst. C.E., proposed still further to lengthen the pipes. Mr. Robert Rawlinson, C.B., M. Inst. C.E., suggested an intercepting sewer, with an outfall to the westward of the town. Sir Joseph Bazalgette, C.B., M. Inst. C.E., recommended an intercepting sewer, with an outfall to the eastward, near Roedean Gate. Messrs. Maclean and Wright also recommended taking the sewage in the same direction, but placed the outfall farther east, namely at Saltdean. The present position, Portobello, was recommended by Sir John Hawkshaw, Past-President Inst. C.E. Although the lengthening of the existing pipes was obviously more economical, yet it did not abolish the disagreeable patches alluded to, and light substances might still be floated near the shore.

The proposal to carry the sewage westward at first sight seems good. The eastern end of the front part of the town is considerably higher than the other, thus a good gradient might apparently be got; and there is a large area of low land on the western side, which might be suitable for irrigation. Against this it was pointed out that the lowest basements in the town are near the Steyne, consequently any advantage of gradient would only be between Kemp Town and the Steyne. Building is also extending, and will no doubt extend, to the westward. Moreover, the prevalent winds are from the westward, hence that side is hardly appropriate for an irrigation farm. The proposal to take the sewage eastward met with more approval. Besides the Engineers already mentioned, Mr. Lockwood, Assoc. Inst. C.E., the Town Surveyor, recommended an outfall in that direction.

III.—Description of the Works.

The work was designed and carried out by Sir John Hawkshaw, the Author being the Resident Engineer. Mr. Matthew Jennings originally took the contract, but the work was finished by Messrs. John Aird and Sons, to whom great credit is due, for having carried it out successfully, in spite of many obstacles.

The intercepting sewer (Plate 8) begins at Hove Street, at the western extremity, runs under the Shoreham Road nearly to the end of the Brunswick Square Lawns, thence passes under the

beach as far as East Street, and, excepting for a short distance at Rottingdean, for the remaining distance lies under the Marine Parade and Newhaven Road to Portobello.

	Feet.
The sewer is of brickwork, and of a circular section, 5 feet in diameter, up to East Street, a distance of	9,900
The diameter is 6 feet, between East Street and the Steyne, a distance of	710
From the Steyne to the Penstock Chamber, Portobello, the diameter is 7 feet, and the distance	27,460
Between the Penstock Chamber and the sea the sewer is partly of brickwork, partly of three cast-iron pipes, 4 feet diameter, laid side by side, the distance being	520
The total distance is therefore	38,590

Or 7¼ miles.

The fall is 3 feet per mile, with the exception of the last mile before the Penstocks, where it is only 1 foot; but as the descent is 2 feet between the Penstock Chamber and the outfall, and as there is a steeper gradient for a short distance near Hove Street, the average fall is about 3 feet in the mile.

		Ft.	in.			
The invert at	Hove Street is	21	6	above low	water of	spring tides.
"	the Steyne	15	8	"	"	"
"	Blackrock	14	8	"	"	"
"	the Penstock Chamber	2	0	"	"	"
"	the outfall	0	0	"	"	"

The discharge of a circular sewer 7 feet in diameter, with a fall of 3 feet per mile, when full, is, according to Eytelwein's formula, 7,280 cubic feet per minute.

Junctions and Catch-tanks. (Plate 10.)

An important difference between old sewers and the sewer now being described is that in the latter a large tank is placed on the tributary sewer just above its junction with the main sewer. These tanks catch the road grit, stones, and heavy materials which would otherwise get into the intercepting sewer.

These catch-tanks are of different dimensions, according to the quantity of material expected. The tank at the Steyne is 40 feet long, and 18 feet broad. Being so much broader than the sewer, the velocity of the current is checked, causing a deposit of the heavy insoluble particles; and the tank being deeper than the

sewer, the deposited materials are not scoured on. All these tanks, as well as the bell-mouth chambers, are ventilated by shafts to the road.

In a junction or tumbling-bay of somewhat peculiar construction, built at Rottingdean for connecting the village sewer, the road is about 50 feet above the invert of the sewer. An ordinary tumbling-bay, in the form of a flight of steps, would have involved considerable excavation; a vertical rectangular shaft was therefore sunk, and flags smaller than the outside section of the shaft were built in alternately on each side; these flags being about 6 feet apart vertically, break up the total fall into a series of smaller falls. As each flag is set to a slope of 3 inches, the bricks above and below being cut for this purpose, there is no tendency for water and not much tendency for other materials to lodge on them. A small catch-pit is built above, and ladders are provided so that the flushers may occasionally clean down the flags.

Side Entrances and Ventilators. (Plate 11.)

There are twenty-four side entrances, including the Penstock Chamber. Besides these, nine of the ventilators have hand and foot irons built into them, so that there are practically thirty-three entrances between Hove Street and the Penstock Chamber; four of these have entrances from the beach as well as winding staircases to the road. Each of the entrances through the concrete wall is provided with a strong sliding door flush with the surface of the wall. When the entrance was double, the main shaft was generally used as a working shaft during progress, the passage to the beach, the manhole on to the footway, and the ventilating passage communicating with a ventilating grate in the centre of the road. Two entrance shafts with ventilating huts were constructed in Saltdean Valley.

Besides the thirty-three entrance shafts which act as ventilators, there are twenty-eight smaller shafts which are only intended for ventilation. (Figs. 9, 10, 11, and 13.) Fig. 9 is the ventilator over a bell-mouth junction. Fig. 10 is an example of a ventilator where the sewer is on the beach, and is intended to imitate one of the wooden huts used by boatmen, with the exception that the roof is of open louvre work. Fig. 11 shows a ventilator where the sewer is under the roadway. Here, as is now general in town sewers, the gratings are not directly over the sewer, but a small pit is interposed to catch stones and dirt. The grates are of cast iron, and are in two parts. The

interior portion can be lifted out without disturbing the outer one or the road metalling. Most of the grates were cast by Messrs. Reed, of Brighton.

When the surface is at a considerable height above the sewer, the ventilators at the lower end of the sewer have irons let into the walls to enable the flushers to get out. Those which are very deep have in addition a special recess, Fig. 13, considerably above the level of the storm overflows, as a refuge for flushers overtaken by a sudden storm.

Overflows. (Plate 10.)

There are three storm overflows in Brighton, their levels being:—

Western.	4 feet	above high water of spring tides.
Central	3 "	" "
Eastern	2 feet 6 inches	" "

On the 21st of December, 1874, six months after the sewage was let in, the central overflow in the main valley had come into operation three times, in July, in August, and again in October, and the other two had come into operation once, viz., on the 4th of October, on which occasion the fall of rain was nearly 1½ inch in twenty-four hours. In the first six months of 1875 the storm overflow only came into operation once. That at the Steyne is shown in Figs. 7. A weir is built in a slanting direction across the old sewer, and the ordinary drainage passes along a new sewer towards its junction with the intercepting sewer. The level of the top of this weir is about 2 inches higher than the old storm overflow farther down the old sewer, so that practically the same relief is afforded to the water as hitherto. This level has been sufficient to prevent the flooding of the lowest basements in case of the water getting past the house-drain flaps, and backing-up the house drains. The storm water is discharged by the former central outfall.

Flushing Inlet.

An inlet has been constructed at the Steyne with penstocks to admit sea-water to flush the sewer; this is generally used at spring tides. The upper end of the sewer is above high water, so flushing water must be obtained by pumping, or by agreement with the Waterworks authorities.

Penstock Chamber. (Plate 9.)

Figures 2 and 3 show the chamber, and arrangements for the self-acting valves, and for working two sets of penstocks, one by which the tide can be shut out in case of the valves not acting, the other for penning back the sewage temporarily so as to flush the outfall at low water. This chamber is provided with a passage to the beach, and with a louvred roof for ventilation. The machinery platform is 3 feet 6 inches above the highest tide, and 4 feet 6 inches above the level of high water of spring tides.

The Terminal Chamber. (Plate 9.)

Between the penstock and the sea the section of the sewer changes from a circle to a semicircular arch with flat invert, and then again, by an arched chamber, to three iron pipes. (Figs. 4.) This chamber is provided with a ventilating manhole.

Outfall.

The iron pipes and the mode of fixing them are also shown in Figs. 4. Each set of three is held together in a frame of greenheart timber, with wrought-iron bolts, and the pipes are retained in line by bolts which pass through lugs cast on them for that purpose. Beyond the mouth of the pipes the sewage runs in a trench only visible at low water during spring tides. This trench has not yet proved a nuisance; but the pipes can always be lengthened if desirable.

IV.—Progress of the Work.

So great a length of the sewer being in tunnelling, care had to be taken in laying out the line. As it was not desirable to sink shafts immediately over the sewer, the entrance shafts, which were in most cases used for working, were generally at one side. In setting out the lines, the Author, having hung two weights, each in a bucket of water, down the shaft, observed above ground, with a theodolite, the angle made by the line joining the two wires with the intended centre line of the sewer, and measured the distance of the centre line from the nearest wire. The theodolite was then taken below, placed at the intersection of the sewer and cross heading, and the same angle set out. Galvanised steel wire was used, and weights of sheet lead, bent in the

form of a six-pointed star in cross section, the object being to check, as soon as possible, both the pendulum movement as well as the torsional rotation of weight and wire. The theodolites had an adjusting plate on the Metford principle, which admitted of a small horizontal adjustment being quickly made without moving the legs of the instrument. Without some such means of shifting the line of collimation of the telescope, the time of setting out or checking the lines would have been greatly increased. Theodolites are not generally constructed to focus on objects within 20 feet; but as it was frequently necessary to read much closer than this, the theodolites were arranged so as to read to within 7 feet from the centre of the instrument. The points set out for the miners, or 'driving points,' were file marks, on a piece of iron fixed into the chalk or brickwork of the heading, from which marks plumb-bobs could be suspended. The best way of rendering visible wires or plumb-bobs was found to be by placing a board, painted white, a few feet behind them, and illuminating the boards with candles. The candles were visible from the telescope, and enabled the observer to find the wire or plumb-bob quickly. The angle being generally nearly a right angle, it was found best not to trouble about exact adjustment of the theodolite, but to measure the angle eight times over continuously round the azimuth circle; four times with the theodolite in the ordinary position, that is, with the focussing milled head to the right; and again, four times with the focussing milled head to the left, that is, with the telescope turned through 180° in a vertical plane. It is only necessary to read the verniers twice, namely, before and after the operation, and then to divide by 8, allowing 360° whenever the vernier has passed through zero. This method of repetition eliminates all instrumental errors. When any error was detected in angle the distance was measured, and the error in arc calculated for that distance. The correction was then made on the piece of iron by a rule. It was found impossible to maintain permanent points from which to suspend the wires down the shafts, on account of jars from the winding and pumping engines, and the wires were hung independently of their former position. In setting out the sewer, curves were avoided as much as possible, long straight lines joined by short curves being the rule. The sharp curve near the penstock chamber was troublesome on account of the number of times it was necessary to shift the theodolite, and the difficulty of fixing up a theodolite exactly at the intersection of two lines. Tables of offsets at the end of each 12-feet length from a chord or tangent were given to

the miners, and they generally set out the right offset, but frequently got wrong through want of accuracy in the measurement of the 12 feet.

Before any brickwork was put in, the Author levelled the work many times from end to end, inserting temporary bench marks and checking the Ordnance bench marks, which were of great assistance. The Author derived great help from small circular levels, fixed to the back of the levelling staffs. Instead of waving the staff backwards and forwards in the ordinary manner, the staff-holder was instructed to keep the bubble in the middle. This was especially useful in the case of steep hills, where the eye is easily deceived as to whether the staff is plumb. Heavy tripods of a special construction, with round steel knobs, were used as pivot points. For measuring down the shafts steel tape was used; it was not graduated, as the tape had to be checked at every measurement by the level-staff, which was used as a standard.

The works were begun in January 1871. In May 1872 the original contractor stopped; but in August a new contract was made with Messrs. John Aird and Sons. This firm successfully completed the work in June 1874, the sewage having been let in on the 21st of May, 1874. The works were done by open cutting between Hove Street and the Steyne, a length of 2 miles, and by tunnelling through the chalk between the Steyne and Portobello, a length of over 5 miles. Between the Steyne and Blackrock the top of the excavation was between 3 feet and 7 feet below the top of the chalk; but only in one case was there a fall of any importance. Three 'bars' were, in this portion, generally used in each length to support the arch; these rested at one end on the last length of brickwork, and at the other on a frame for that purpose. These bars were drawn before 'keying-in,' and it was rarely that any timber had to be left. Elsewhere bars were frequently but not invariably used.

On the contract drawings the brickwork was shown to be 9 inches thick, but between Rottingdean and the Penstock Chamber the thickness was increased to 13½ inches, and between the Penstock Chamber and the sea to 18 inches. All the brickwork of the sewer is set in Portland-cement mortar (2 of sharp sand to 1 of cement), but the walls of the Penstock Chamber are set in greystone lime mortar.

Gault pressed bricks, or bricks made at St. John's Common, near Burgess Hill, were used in the inverts; and ordinary Gault or stock bricks in the arches; also a few excellent bricks from

Bishop's Waltham. Experiments on a number of these bricks, by weighing them when dry and when saturated with water, gave the following results:

Description.	Average Size.	Weight when dry.		Weight per Cubic Inch when dry.	Weight of Water absorbed per Cubic Inch.
	cubic inches.	lbs.	oz.	ounce.	ounce.
St. John's Common . . .	91	7	0	1·23	0·05
Bishop's Waltham	98	7	2	1·16	0·07
Stock	94	5	0	0·85	0·13
Gault	103	6	4	0·96	0·16

Two bricklayers were employed on each 12-feet length of work of the 7-feet sewer. They were paid 10*s.* each for each 12-feet length of 9-inch work, and 15*s.* each for each 12-feet length of 13½-inch work. The number of labourers of course varied according to the length the bricks and the 'compo' had to be run. The best bricklayers sometimes did as much as six lengths of 13½-inch work each in the week, thus earning £4 10*s.* The labourers got each rather more than one-half what the bricklayers earned.

Brick blocks of eight whole bricks and four half bricks were used when the bottom was wet. These blocks were generally made of stocks, as the stock brick seems to take hold of the cement better, and at any rate sooner, than the others. This was important, as the blocks were made on the ground, and had rough handling in being loaded into skips, lowered down the shafts, run along the heading, &c. Pressed bricks, in consequence of a glaze they get, are not good for this purpose.

More than six million bricks were used—sixty-three courses being required in the inner ring of the 5-feet sewer, and eighty-six courses in the 7-feet sewer. When everything was in good working order, about 400 lineal feet of brickwork in tunnelling were executed per week. On one occasion a length of more than 500 feet was accomplished; but a good week was generally followed by a bad week.

The fact that the water in the wells at Brighton and at Rottingdean, though fresh, rises and falls with the tide, and the number of fresh-water springs on the beach at low water between Brighton and Portobello, led to the expectation that considerable pumping would be required. Soon after the work was commenced, in February 1871,

water was met with in a shaft near Ovingdean, at a level of 5 feet above the invert of the sewer at that point, or rather more than 1 foot above the level of mean tide. When the works were stopped, during the summer of 1872, the opportunity was taken to gauge the fluctuation of the water in the shafts; and it was found that the level rose with the tide, being highest two hours after high water. It was also considerably higher at springs than at neaps, and when the wind was on shore than when off the land. Pipes were laid under the invert to carry off the water, while the brickwork was being put in. When the junction was made between the brickwork from one shaft with that from the next, the pipes were plugged, or closed by a valve built in for that purpose.

Under the sills at Portobello iron pipes were used, which were afterwards filled with Portland-cement grout. So great was the pumping that the wells in Rottingdean and at the Coastguard station at Portobello were seriously affected. The contractors state that for a considerable period they pumped 15,000,000 gallons every twenty-four hours, or 10,000 gallons per minute, the water in most cases being raised about 30 feet. At this time thirteen pumps, about 20 inches in diameter, were employed. To work these one 50-HP. stationary engine, and eight portable engines averaging 14 HP. each were used. The portable engines sustained considerable wear and tear, especially in the tubes and fire-boxes, on account of the brackish water.

The water in the chalk gave considerable trouble in setting the brickwork, especially in the event of fissures. In such cases a small longitudinal channel was generally cut on the edge of the fissure; and if the rim was not high enough to contain the water, a small clay wall was raised upon it. This channel conveyed the water beyond the 12-feet length of brickwork under construction down into the pipes below the invert. The brickwork was then proceeded with, blocks being used all along the fissure. An iron pipe was built in the wall opposite the fissure, and after the length was completed the water in the fissure was allowed to pass through the pipe on to the invert, and the longitudinal channel was filled up for some distance from the end of the length with rammed clay. The water ran through this iron pipe for several days till the brickwork was thoroughly set, and till a considerable length of work had been completed in advance. The pipe was then plugged, and when the plug was tight, a brick was built-in in front, for which purpose the pipe had been kept back the proper distance from the face. Flags were occasionally laid over fissures; in one case, viz., at a length between Saltdean and Porto-

bello, where a strong spring had shown itself, the water of the spring was conveyed some distance in iron pipes independent of the pipes under the invert. Flags were put over the spot where the spring came up so as to force the water through the pipes to a sumphole some distance off, whence it passed back through the ordinary pipes to the pumps. The brickwork was then put in, and when well set the auxiliary iron pipes were plugged, and the work continued. The object of this was to obviate the necessity of pumping the whole delivery of this spring while the rest of the work was in progress. Occasionally the water crept between the bricks and the chalk. When this was the case a groove was cut in the chalk to admit an extra ring or two of brickwork.

The ventilation of the sewer during the progress of the works was good in every portion where there were two openings. Where there was only one opening the air in the heading became bad at about 500 feet or 600 feet from the shaft, and openings to the cliff were frequently made. In one case a length of more than 1,000 feet was driven from one shaft, but a fan was used for ventilation. Where there was more than one opening the draught was generally so strong that doors had to be put across the heading to prevent the candles being blown out.

The total cost of the work to the Board has been about £100,000.

The cost of a lineal foot of the 5-feet sewer, which was built almost entirely under the first contract and in open cutting, was 29*s.* The cost per lineal foot of the 7-feet sewer, 9-inch work, which was done by tunnelling, was 27*s.* under the first contract, 41*s.* under the second. The extra cost of 3-ring work (13½ inches) over 2-ring work (9 inches) was, under the first contract, 12*s.*, under the second 16*s.* per lineal foot. The cost of a ventilator varied from £20 where the sewer, as at Cliftonville, was not far from the surface, to £160 where the ground-level was, as at some places on the Newhaven Road, from 150 feet to 160 feet above the invert. The ventilators, including catch-pits, gratings, &c., may be said roughly to have cost about £1 per vertical foot.

The staff now employed on the works under the Town Surveyor is one inspector and six flushers, including two men who look after the penstocks at Portobello.

By letting water in at the Steyne at spring tides, and by occasionally keeping the penstocks shut till low water, the sewer is cleansed of all deposit between the Steyne and Portobello, so that it is not necessary to raise any deposit out of the sewer along this length. This is chiefly owing to the greater part of the

deposit having been intercepted in the catch-tank at the Steyne, which is cleaned out nearly every night. The other catch-tanks do not require to be cleared so frequently, but their utility, and the consequent saving both of labour and of wear and tear to the brickwork of the intercepting sewer, have been clearly shown since the opening of the work.

The Paper is accompanied by a series of drawings and diagrams, from which Plates 8, 9, 10, and 11 have been compiled.

[Mr. H. M. Brunel

Mr. H. M. Brunel gave the lengths of some of the old outfall pipes. The central outfall at the Steyne was 1,760 feet in length. The Brunswick Square outfall did not quite reach low-water mark spring tides; and in 1869, when the agitation for the intercepting sewer led to the plans being prepared, an outfall pipe was being laid at the western extremity of the parish of Brighton, 2,000 feet long. The eastern outfall pipe was 800 feet long, and reached just below low-water mark. The new one put down at Cliftonville in 1869 or 1870 went some way below low water.

The middle piece of the ventilating grate referred to in the Paper could be taken out, and a man could get down comfortably to clean out the catch-pit.

Mr. Hayter remarked that a short time ago he asked the Inspector in charge of the intercepting sewer whether, since it had been completed and in operation, any mistakes in construction had been detected. The Inspector stated that where the King's Road and Western Street branch sewer joined the intercepting sewer, which it did by a somewhat steep incline, after a shower of rain the road detritus was washed out of the catch-tank and deposited in the intercepting sewer towards the West Pier. That could have been remedied if the catch-tank had been made somewhat larger, as the velocity of the flow would then have been decreased, and the detritus would not have been so easily washed out. There was also a slight tendency to deposit between Roedean and Saltdean, where the flow was checked by the rising of the tide, but the deposit was readily removed by flushing. There had been some slight complaint in one or two quarters as to the ventilation of the sewer, in respect to which the people at Brighton were very particular, and properly so. He believed, however, there was little foundation for the complaint. There were ventilators about every 200 yards. They were at first intended by Sir John Hawkshaw to be at longer intervals; but at the time the Prince of Wales became so alarmingly ill from fever, contracted as some alleged from want of ventilation in a sewer, there was a great outcry everywhere for increased ventilation in sewers, and the distance was reduced to 200 yards. A furnace and chimney, to increase the velocity of the air through a portion of the sewer, were now being erected about 1 mile to the eastward of Kemp Town, and if considered desirable at any time, a fan could be added. The contractors had met with many difficulties. On taking the work materials of all kinds began to rise in price, and the pumping was greater than had been expected. They however completed the contract exceedingly well. The sewage when

entering the sea at the outfall dispersed very readily. Occasionally after northerly winds there was a slight deposit on the shore; but the outfall was far removed from population.

Capt. GALTON asked at what period of the tide the sewage was delivered into the sea; and whether the Brighton Corporation, before adopting the present scheme, had tried the A B C system? It was stated in the Paper that the sewer from the Steyne to Portobello was flushed by admitting water into it at high water, and allowing it to discharge at low water. Was the bottom of the sewer at the point of discharge below low water at ordinary tides, so as to increase its discharging power at and near low water?

Mr. H. M. BRUNEL replied that it would if there was rain to fill the sewer. He also stated, in answer to Capt. Galton, that there was a back valve to prevent the entrance of the sea water.

Mr. HOMERSHAM said he had driven numerous small 'adits,' or tunnels, in the chalk strata below the line of saturation, and in many cases had found no difficulty in shutting out a large portion of the water to relieve pumping, by filling the fissures with dry deal wedges, first rounding the edges of the fissures. It required some manœuvring, for too hard driving would split the chalk. If the water were wanted afterwards the wedges could be taken out. The water did not usually issue through the mass of the chalk, but came out in places, through fissures and small cracks: a large quantity could often be shut out in the way he had mentioned.

Mr. GILBERT REDGRAVE inquired what was the amount of sewage and the quantity of silt that had to be removed daily. In the improved method of constructing sewers it was usual to prepare very capacious chambers on the course of the main sewer. It had been stated, indeed, that the catch-tank at the Steyne was 40 feet long, and that it had to be cleared out daily. If in the course of a main outfall it was necessary to provide for the removal of silt, engineers should study the best position for those chambers and provide ready means of getting at them. They should, if possible, be cleared out on a level, so that the silt would not require to be carried up on the shoulders of the men; and the work should be done at night. It would be interesting to know the proportionate quantity of silt to the whole volume of sewage. No doubt it would vary with the soil, the weather, and other atmospheric circumstances. With regard to the ventilation of the sewer, it had been said that it was proposed to employ furnaces in one of the shafts to draw out the air—a furnace not at

the outfall, but 1½ mile or 2 miles from the lowest point of the sewer. Was it intended that it should draw air only from the higher part of the sewer? If so, what provision would be made to prevent it drawing from the outfall or the penstock chamber? In some sewers, recently constructed, it had been found best to ventilate from the highest point of the sewer; and the question of position, he believed, had never been satisfactorily answered. It would be interesting to have some further explanation on that point. It certainly seemed unusual to employ artificial ventilation at a point midway between the town and the lowest point of the sewer. There was a great difference between the cost of the sewer under the first and under the second contract, and he should be glad to know the reason. It seemed in this case that the cost of the tunnelling had been cheaper than that of the sewer in open work, which was probably due to the easy character of the excavations in the chalk. In other sewage works of which he knew the cost, the tunnelling had averaged a good deal more than the work in open cutting.

Mr. R. W. P. Birch asked how often it was found desirable to use special means of flushing, and what quantity of extra water was used. With regard to chimneys too many particulars could not be given. He understood Sir Joseph Bazalgette and other men of eminence reported, in connection with the London sewers a few years ago, that it was quite useless to attempt to ventilate any large system of sewers to one point by artificial means.

Mr. Harrison, President, said that, in considering the drainage of such a town as Brighton, the intercepting sewer formed but a small part of the whole question, because it was quite as essential to ascertain in what manner the sewage was conducted through the town as it was to know what was done with the outfall sewer. Nothing was more treacherous than the fact of a town having a high level like Brighton, leading to the belief that as there were abundant means of fall and drainage everything was satisfactory. The question of ventilation in the town had, in many cases within his own knowledge, been entirely neglected, and the gases had been allowed to accumulate in the higher parts of the town, where, if anywhere, fever was sure to be found. He hoped that attention would be directed to the means taken to ventilate the whole of the upper part of Brighton.

Mr. Abernethy remarked that the Paper had been confined chiefly to the construction of the intercepting culvert and outfall at Brighton. Without adverting to the general system of the drainage of that town, he would refer to the general question of the

disposal of sewage in various cities of this country. As a general rule, sewage had been discharged into rivers, and hence their extraordinary state of pollution, from which there appeared to be no remedy, notwithstanding the many Government inquiries and reports on the subject. As Sir Joseph Bazalgette was present, he wished to take the opportunity of expressing an opinion he had long formed, that the half measure of discharging the sewage of the metropolis into the Thames at Crossness would eventually turn out a source of great pollution to the river. The result up to the present time had been that the original clean gravel bed of the river was lined with a deep coating of sewage mud. He had been informed that for some time past the river at that point had been in a normal state; but that did not alter his opinion of the final results to be expected from thus discharging the metropolitan sewage. By the alteration of the river in all probability at that point a state of equilibrium had been established between the forces of the river current and the sectional area of its bed; but he apprehended that the lining of mud over the original gravel bed had been, or was being, prolonged gradually down the river, so that eventually it would become a source of great sanitary annoyance, and to some extent might impede the navigation of the river. He was afraid that the pollution attending the discharge of sewage into rivers was likely to take place also to a certain extent upon the foreshore of many marine watering-places, from the discharge of sewage into the sea within a short distance, generally about low-water mark. He had been recently consulted with regard to the sewage of Ramsgate, and he found that the whole of the sewage of the town was discharged at low-water mark quite close to the Western Pier, the result being that when the foreshore was uncovered the nuisance was exceedingly great. He had ascertained that at certain periods of the tide, and of the discharge, the sewage found its way directly into the harbour, and even beyond the Western Pier, on to the foreshore, which was extensively used as bathing ground. He had some experience as to the value of the deposit derived from sewage. Many years ago, an intercepting culvert had been constructed for the sewage of the city of Aberdeen, which, like Brighton, lay generally on hilly ground above the level of the culvert. The sewage was all discharged at that time at one point in the tidal harbour outside the dock, and had to be removed by dredging. There was an extensive range of sandhills between the city and the sea, and the material raised by dredging had been used in covering the whole of the foreshore within high-water mark with the

deposit from the sewage, converting it into valuable ground for agricultural or general purposes; and he apprehended that if the outlet for the sewage of London had been prolonged as far as Maplin Sands, a large area of waste ground might have been reclaimed for agricultural purposes. This would have been a preliminary step to the ultimate discharge of the sewage water into the sea. He believed a remedy for the present state of things would eventually be found in precipitating the solid constituents of the sewage, and passing the effluent waters into the rivers or into the sea. In the case of the river Thames, he thought that the standard required for effluent water was a great deal too high. He could not imagine that sewage water simply impregnated with ammonia and other salts, and free from solid matter, would cause any injury whatever to the great volume of the water in the river, and certainly it would be innocuous in the sea. Companies had been formed in order to use the deposit for commercial purposes; but they had failed, because they attempted a great deal too much. All that was required was to precipitate the solid constituents, to deodorise the material so precipitated, and to pass the effluent waters into the sea. That was the only way to preserve rivers and foreshores from pollution. A similar intercepting culvert to that at Brighton had been made at Aberdeen, and it was found that during the period when the tidal valve was closed and the sewer had no outlet, the noxious gases generated in the main culvert found their way up the various drains and subsidiary sewers into the higher part of the town; and he apprehended that, with the means of ventilation adopted at Brighton, when the tide was up and the outlet closed, and also when the culvert was flushed with a large body of sea water, the same result would follow. At Aberdeen an attempt had been made to remedy the evil, which to some extent had succeeded, by placing metal valves on the outlets of sewers entering the main culvert. These opened when a slight amount of sewage got behind them; but, as a general rule, they remained closed. No more important question could be brought before the Institution, and he thought that a good subject for discussion would be,—the best means to adopt, in a sanitary point of view, independently of commercial considerations, for the disposal of the sewage of great cities.

Sir Joseph Bazalgette said the Paper was one of peculiar interest, opening up as it did the large question of how to dispose of the sewage of towns. He might call it the "vexed" question, because he was quite sure that a variety of opinions would be expressed concerning it. It was always more easy to speak of a

Paper when one differed from the Author's views, and he now found himself in the difficulty of agreeing very much with the general features of the scheme propounded in the Paper, which were in accordance with what he had carried out in London, at Weston-super-Mare, and at St. Leonards; with what he was now carrying out at Torquay, and had obtained an Act of Parliament for last year for West Kent, and also with what he had recommended for many other places. The principle of simply diverting the cause of mischief to a locality where it could do no mischief was one which, he believed, had been attended with considerable success. He was surprised to hear it stated that in consequence of the drainage of London, a large accumulation of mud had taken place in the river at the outfalls, and that there was a prospect of it impeding the navigation. He had never before heard such views expressed by any member of the Institution. He would ask whence the facts were gathered on which these conclusions were grounded. Since the metropolitan outfalls were first opened, he had had soundings taken in their neighbourhood, and he found that there was, at the present moment, less accumulation of mud there than there had been before the outfalls were established. The question was raised some time ago, when it was proposed to carry the sewage of London to the Maplin Sands. The company formed for that purpose failed to raise sufficient funds, and an effort had been made to put pressure upon the Metropolitan Board of Works to induce them to carry out the scheme. The cry was then raised that the Thames was silting up. Mr. Rawlinson was on that occasion appointed a commissioner to investigate the matter, and after a patient hearing of all that could be stated on both sides, he came to the conclusion that there were no solid grounds for the complaint. It was, however, determined that if an accumulation should take place, it should be incumbent upon the Metropolitan Board of Works to dredge, if called upon to do so by the Conservators of the Thames. Notwithstanding that arrangement, they had never been called upon to dredge that portion of the river. His soundings agreed with those of the Thames Conservators, although the conclusions at which they arrived differed, and it appeared that while during two years there had been an accumulation, during the next two or three years there had been a large decrease. Any one who would observe what was going on in the Thames would discover that the accumulations in the river were governed by much larger forces than those to which Mr. Abernethy had alluded.

He thought the mode of disposing of sewage adopted in London

and in seaport towns—that of intercepting sewers, as far as possible by gravitation, with an outfall at a point where no nuisance could be created—had been successful. It had been said, and would no doubt be repeated, that, in forming such outfalls, an article of great value was thrown away, while guano was being imported at a cost of £10 per ton. No doubt sewage was an article from which one would expect a return; but for various reasons it was exceedingly difficult to turn it to profitable account. First there was what might be termed "the water difficulty," while it was of the greatest advantage to towns to have an ample water supply to carry off the sewage, that ample supply formed one of the great difficulties of dealing with it at its outfall. Then there was "the land difficulty." In the neighbourhood of large towns land could only be obtained at a large cost. Those two difficulties stood in the way of what otherwise might be a most successful mode not only of purifying sewage but also of applying it to profitable account, namely, by means of irrigation; and it had been mainly on account of these and of the necessity for purifying that any profit from sewage irrigation had so rarely been realised. Croydon would no doubt be instanced as a case in which the system had been profitably applied. He might say at once that in all cases where the sewage was properly applied to land of sufficient quantity it would be purified; but there were many instances in which that could not be done. When Mr. Marriage, the tenant, worked the farm at Croydon, he paid the Corporation 30*s.* an acre for it, but the Corporation were paying £10 an acre, so that while he had been making a profit they were making a loss; and when the Corporation afterwards took to the farm themselves, they continued it at a loss. It was only in some few exceptional cases, where land well suited for the reception of sewage could be obtained under sufficiently favourable conditions, and where the sewage could be applied by gravitation (it generally had to be pumped from the lowest point to be drained on to the land), that it could be made to give a profitable return. The land difficulty had been attempted to be met by reducing the quantity of land, and by substituting for broad irrigation intermittent downward filtration. This was introduced by an experiment of Dr. Frankland, and was first tried at Merthyr Tydvil, where it was proposed, instead of applying the sewage from one hundred people to an acre, to apply the sewage of one thousand people. In some instances it had been proposed to go to the extent of three thousand. At Merthyr Tydvil, however, the conditions were very favourable. There was a bed of gravel 50 feet deep, with

a porous soil, and the sewage could be applied by gravitation, there being an abundant fall. The result was that the system had been a success; but the Engineer stated that he would not permanently apply more than the sewage of five hundred persons to an acre under those favourable circumstances. The plan was to divide the farms into three portions: one-third had the sewage poured upon it for a year, the other two-thirds remaining at rest. When the land was once charged with the sewage it had two years to recover itself. The one-third was again divided into thirds, each third having sewage poured upon it for eight hours, during which the other two-thirds remained at rest; the object being that the sewage might filter through the land, and that the air might pass through, so that it might be oxidised and purified. That, no doubt, was a very efficacious mode; but if on the average the sewage of a thousand people to the acre was applied, it was in reality for the time being applying the sewage of nine thousand persons to the acre. The scheme was, at the present moment, a popular one, but it was in great danger of being carried to an injurious excess. In the case of a clay soil, or where it was difficult to obtain broad acres of land without a large expenditure of money, it was very easy to say, "We will have recourse to intermittent downward filtration;" but he believed that the hobby was now being ridden so far that, unless it was checked, it would lead to very disastrous results. With regard to the water difficulty, it had been proposed to meet it by the use of all kinds of chemical agents to produce precipitation and to allow the water to pass off in a pure condition. No doubt most members had seen upon the table in a committee-room or a lecture-room some of those processes tried, and apparently with great success; but what had been the practical result? The lime process was tried at Leicester twenty-five years ago, and it proved a gigantic failure; first, because it was exceedingly costly; and secondly, because the more lime put into the sewage the more deposit was produced, and the deposit being valueless, it was extremely difficult to get rid of it. Then there was the phosphate sewage process, the A B C process, and a variety of other methods of disposing of sewage. Most of them had been tried by companies, and although the shares had gone up for a time, the bubbles had burst; and he knew of no case at the present moment that could be referred to, in which these processes were being carried out except as a palliative, and then at such a cost that the tendency was always to shirk the process of purification as much as possible. The sewage of Birmingham was now being utilised by the lime process under

the able direction of Mr. Hawksley, Past-President Inst. C.E., and it was being carried out as well as it possibly could be; but he thought Mr. Hawksley himself would admit that it was only a palliative, and that it was not such a process as could be applied to most towns. The system required large open deposit reservoirs, the sewage being pumped by troughs on to the land, then spread over the land and left to dry and afterwards dug into the ground. If such a mode were adopted for places like Brighton, Bournemouth, Torquay, and St. Leonards, those towns would soon be deserted by their visitors and would be utterly ruined. It had also been proposed to do away altogether with water-carrying and to revert to earth closets, to adopt the Liernur system and various 'midden' systems. He ventured to say that, whatever difficulties there might be in disposing of sewage when mixed with large volumes of water, such was the feeling of this country that the people would never revert to systems like those he had mentioned. Such processes might answer under certain circumstances. The earth system, for instance, might do very well in the country, where a gentleman had his own ground and his own servants to carry away the refuse, but it would never do to have carts going through the streets of a town, carrying dry earth, and men going through the houses with pails to carry up the fresh earth and to remove the refuse. People would rather grapple with the difficulty of disposing of sewage mixed with water than revert to such a state of things. The earth system, moreover, would not do away with the expense of constructing sewers, because the washings from sinks, and other offal of that kind, would have to be carried away underground, so that sewers would still be a necessity. Not wishing to occupy the time by reviewing many other processes which had been proposed, and all of which had engaged his earnest attention—for he had looked forward to the time when what might still be called the sewage difficulty would be surmounted—he came back to the conclusion that sewage must, for the present, be regarded as an enemy to be got rid of, and not as a friend to be courted and turned to account. Each of those processes might, under certain circumstances, be adopted with advantage; and it was for the engineer to consider which was the best. In some cases, as in many inland towns, it had been difficult to obtain an outfall, and in such cases the principle of combination was very advantageous. It was a principle which he had recommended for the towns in the valley of the Thames above London. There was a large number of small towns which could not go to the expense of carrying sewage to a great distance where a suitable outfall could

be found, but if they would unite together, what was impossible for one would become possible for the whole. The difficulty in such a case was not an engineering one, but it was the difficulty of inducing the different authorities to combine for their general good. One of the advantages of combination was a great economy in construction. If a sewer of 1 foot in diameter was required for the drainage of one town, a sewer of 3 feet diameter would suffice for the drainage of ten such towns, because the area was as the square of the diameter, and the velocity was much greater in a large sewer than in a smaller one. The excavation for a sewer 1 foot in diameter was the same as the excavation for a sewer of 3 feet in diameter, and the only difference in cost was in the size of the sewer itself. If by increased volume increased velocity was obtained the fall might be saved, and in that way there would be a saving of pumping. Again, instead of having a variety of pumping stations for each town, if they all combined together the staff required for one station would do for half a dozen. In regard to sewage, as in regard to other matters, there was strength in combination, by which things otherwise impossible might be accomplished.

Mr. Monson remarked that the question now to be considered was, whether it was expedient to adopt large outfall sewers. He did not propose to go into the various processes for dealing with sewage; he would confine his remarks entirely to the Paper, but he would endeavour to make his observations apply to large intercepting outfall sewers generally. The Author of the Paper had brought out boldly the difficulties of pumping, the extraordinary depth of cutting, and the method of overcoming water from the chalk. He had, however, abstained from stating the objects of the work, and the benefits which the people of Brighton had derived from so stupendous an undertaking. If a longitudinal section had been included in the drawings the faults of the system would have been at once apparent. The work was called the Brighton Intercepting and Outfall Sewers, and the object in view was to remove the sewage from the town in such a way as not to be offensive either to sight or smell, and to improve the health of the place. He learned that the range of the tide was 22 feet, that the invert at Hove was 21·6 feet above low water, and that the point of outfall was exactly at low water, so that the sewage was never entirely discharged; also that six flushers were employed, showing that there must be a large amount of sludge deposited: it followed that putrefaction was always going on, and a large quantity of sewage gas was constantly being given off.

Again, the sewage for a good part of the day was blocked in by the tide; the sewage therefore headed up, and there being no current at all, sludge was freely deposited. The sewer thus became, not a channel for sewage, but an elongated cesspool—a manure tank, which during a storm and high tide might be filled from end to end. The whole of the sewer was covered, ventilators were put in, but their united area was small compared with the volume of putrefying sewage. What took place? The tide rose, the sewage could not escape, it headed up further and further, and the sludge was deposited thicker and faster. Again, sewage gas was constantly forming, and the space for it being contracted by the rise of the sewage, it became more and more concentrated, and was at length forced into the houses of the unsuspecting inhabitants. It thus failed in its chief object, to improve the health of the place. He believed the resident medical men considered the scheme the reverse of satisfactory. Then with regard to the sewage, the insoluble portions were not removed, but were discharged at dead low water. It followed as a matter of course that this would come in with the tide, and be cast upon the shore; and besides, the salt water would precipitate a large quantity of the soluble elements of the sewage. He believed the sewer was constructed at too low a level. A main sewer ought always to be self-acting and self-cleansing, and this should have been so laid that the sewage could be continuously discharged from it even at high water. The drainage of the lower part of the town ought to have been separately dealt with, and carried along shore, the old sewers being utilised to discharge the surface water. The sewage being thus reduced in quantity, a smaller sewer would have sufficed, which would have reduced the expense. As regarded treatment, the insoluble portions ought to be removed from the sewage before it was discharged. To do this it should be received into a tank and treated with lime, there being no better method than that which had been so well conceived and so ably carried out at Birmingham by Mr. Hawksley, Past-President Inst. C.E. Such an arrangement would have met the circumstances of the case most admirably. The work under discussion did not appear to be an outfall sewer at all. The character of sewage seemed to have been left out of account. The arrangements were such as might be made for carrying off clean water, but were most improper for disposing of sewage. Putrefaction and noxious gases had been entirely ignored, and sludge was not taken into account. The only idea of disposal seemed to be, "Throw it into the sea, and disregard all future consequences." The work

was a failure in a sanitary point of view—an elongated cesspool of the worst kind, generating sewage gas to an enormous extent, which, having no means of escape, was offensive to smell and injurious to health. It was a failure as regarded the removal of the sewage from sight, for it came back with the tide. It was a failure in an engineering point of view, being constructed at a wrong level, and being much too costly. It was altogether an example of what to avoid.

Mr. Aird said he had thought, as one of the contractors for carrying out the work at Brighton, that he and his firm had been associated with an engineering undertaking which would have obtained credit for every one concerned in it, and of which they might justly feel proud. He still entertained that opinion, notwithstanding the severe strictures of the last speaker. Having had a great deal to do with sewage work, he could conceive nothing better than the outfall system adopted at Brighton. The engineering arrangements had been considered as carefully as possible, and he thought the same thing could be said with regard to the construction; so that Brighton might fairly take credit for being in as good a position as regarded its general sewage arrangements as any town in the country. With reference to the cost, the members should not take the figures given as an accurate criterion. Not that Mr. Gamble was incorrect in his statements, but it was pretty generally known that the actual cost of the work was largely in excess both of the estimate and of the money paid under the contract. His firm was unfortunate enough to lose £40,000 in carrying out the work. He mentioned that circumstance in order that it might be taken into account in any similar undertaking, and also as bearing upon the remarks made by Mr. Redgrave on the comparative cost of the work in the tunnel and in the open cutting. It had been an error in judgment to take the work at the price named. It was brought about by the desire, which most contractors felt, to complete works of great interest which they thought might add to their reputation, and which they took a considerable amount of pleasure in following up. But the cost was enormously increased by the extraordinary rise in the price of fuel and materials generally, and more than all by the great difficulties in dealing with the water. The quantity of water previously estimated was nothing in comparison with that with which they had to deal. There were one or two points in which he now thought they were wrong in the course pursued. First with reference to the pipe under the 7-feet sewer. It was found necessary in carrying out the works to put the pipe under the

sewer with the view of bringing water to the pumps, and unfortunately the contract threw upon the contractors the responsibility of finding any pipes that might be necessary for temporarily draining the works. That which read as a small matter in the contract turned out to be a very serious one, inasmuch as it necessitated a line of pipes between 5 and 6 miles in length continuously under the sewer, laid at a very great depth, where there was a large amount of water to be dealt with. Under the circumstances, instead of using earthenware pipes, he believed it would have been true economy if they had used iron pipes throughout the whole length. It was difficult at all times to make the joints of the earthenware pipes sound, and he believed that they pumped an enormous quantity of water more than they ought to have done. He also thought that an error in judgment had been committed in not dealing with the question of water supply for the machinery, and laying down piping 6 or 7 miles in length to supply fresh water. They endeavoured, without success, to make some arrangements with the inhabitants along the line so as to divide the expense. The negotiations took up a considerable time, but ended in nothing towards facilitating the object in view. Having regard to the pumping at the end of the work being very large, it was in reality a great misfortune, inasmuch as all the boilers had to be fed with brackish water, except that which was taken by water-carts. The pumps broke down many times in consequence, and a bad effect had been produced upon the engines sent to do the work. The last point to which he would refer was the position of the sumps. In that respect, too, a mistake had been made. They commenced by sinking them in the valleys, saving in that way a depth of about 60 feet in the excavation for the shafts, and some expense in lifting the material from them; but later on, when it was found that there was so much water to contend with, they sank several shafts in the high ground, where the water was much less than in the valleys. He believed that the work would have been carried out at less cost if in the first instance the shafts had been sunk in the high ground, so as to have the sumps there, and the work carried across the valleys with great rapidity. The ventilation, he thought, might be better provided for by pipes at such points as might be thought most convenient with regard to levels, those pipes being carried at several points either to high ground, or by the side of, or, if necessary, through houses which might be bought for the purpose.

Mr. Philip C. Lockwood remarked that, having been Borough Surveyor for Brighton for seventeen or eighteen years, he had had

some opportunity of watching the progress of the sewage and drainage of the town. When he first went to Brighton there was a trunk in the centre of the town opposite the central valley, to carry the sewage to low-water mark, but being a structure 10 feet in height, made of wood, and subject to the action of the waves, it leaked very much, and the sewage was really delivered immediately on the shore, and was very offensive. When he was appointed surveyor he proposed to obviate the evil by putting in a pipe which would extend beyond low-water mark, with an overflow for storm water. Opinions were adverse to any expenditure of money, and it was difficult to get a vote for the purpose. A 12-inch pipe was, however, put down to low water, which proved so successful that he was afterwards enabled, being supported by the opinion of Mr. Hawksley, to induce the Corporation to lay a still longer pipe, 3 feet in diameter and 1,760 feet in length, and another 2,000 feet long at the western district, extending 1,500 feet beyond low-water mark. He believed that no pipes of that kind had been laid elsewhere. The lowest depth of water at those points was from 8 feet to 16 feet, so that at all times the mouth of the pipe would be at that depth below the surface, and the sewage would be delivered into a current of from 2 to 3 miles an hour. He fully appreciated the comprehensive way in which the matter had been dealt with by Sir John Hawkshaw, and he also admired the care and ability displayed by Mr. Gamble; at the same time he felt that perhaps, in a sanitary point of view, they were not better off than they had been with the outfall pipes previously laid. The sewage was delivered by the pipes moment by moment into a current, and disposed of before it could reach the shore. With a south-west wind it might at times reach the shore; but before it could do so it would be so oxidised by the air and the water as to be practically harmless, which indeed he had found it to be by his own personal observations. There was, however, to be seen when it rained a yellow patch of water, which gave alarm to the visitors when they were told what it was. Unfortunately, Brighton and Hove, although practically one town, were under separate systems of local government, and at the western boundary of Brighton, where it joined Hove, there was at the time referred to an outfall which only went to low-water mark, and which was a serious cause of offence, the sewage being delivered at a point where there was but a small quantity of water, just at the edge of the tide. When sewage was delivered in sufficiently deep water there was really no offence at all, although occasionally particles of sewage matter not soluble might

be seen by persons swimming or rowing, which of course was not desirable. He believed a mistake had been made in taking the outfall immediately opposite the centre of the town. He quite endorsed the sentiment of Sir Joseph Bazalgette, that sewage was to be regarded as an enemy to be driven out in the most peremptory manner. It should be removed in the shortest way; and the shortest or nearest way of disposing of it was to take it out straight from the valley with the best possible hydraulic inclination. The discharging power of the present outfall sewer was about 8,000 cubic feet per minute. The three pipes previously used discharged about 10,000 cubic feet per minute, the gradient being much sharper, the intercepting sewer producing a velocity of about 209 feet per minute under the most favourable circumstances, whilst the pipes, owing to their superior hydraulic inclination, gave a velocity of 580 feet per minute, and they had the advantage of discharging into deep water. They had been in use for nearly ten years, and during the whole of that time they required no attention whatever. They still served to receive the storm overflow from the new sewers. The flattest gradient in the old sewers was 1 in 218, and the sewage was taken entirely to sea. By the present system about ten loads of silt were lifted from the catch-pits every week. A short time before the present project was started, he carefully examined the mouth of the principal outfall pipe, and he found that the bed at the bottom of the sea was perfectly clean. The outfall scoured for itself a clean place, and there was no sand around it—nothing but white chalk, which could be seen from a boat when the water was clear. There were nuisances existing, as would always be the case, from seaweed and other matters, and to a certain extent the shore might be affected, though he had not been able himself to detect that it was affected by the sewage. The examination had been most carefully made both in-shore and with the assistance of diving apparatus in deeper water, and numerous samples of the sand and water likely to be affected were submitted to chemical examination. Certainly it was not desirable to have the outfall at the point to which it was at first taken, and it was perhaps better that the sewage should be taken 4 miles away. But it was not entirely disposed of: the flat sewer was still there although underground, the ventilators were in the high road of the principal drive, and some of them were placed near the centre of the town. There was certainly a prejudice against them. In the late frosty weather the steam from the ventilators could be seen coming up in the middle of the street. Nor ought the evaporating surface of the sewer to be lost

sight of. Multiplying the length of the sewer by the diameter, the evaporating surface covered with sewage or sewage deposit was about 250,000 feet, a very large surface, constantly throwing off sewer gas, which must be discharged somewhere, and no doubt the tendency was for it to be driven up the tributary sewers. That might prove a source of danger. He had, therefore, proposed, and Sir John Hawkshaw had concurred in it, to put a tidal valve at a place called 1A, about 750 yards east of the toll-gate, halfway between Brighton and Rottingdean; an ordinary wooden tidal valve, with an iron frame, which would open for the sewage and shut out any air coming from Portobello. A length of 2½ miles of the eastern end would thus be cut off, and this was, no doubt, the worst part, because being tide-locked there was a great tendency for sludge to be deposited. When the sea was up the sewer was tide-locked, and when down it was subject to draughts; and for that reason he had proposed to put in the valve. It was also proposed to build at that point a shaft 100 feet high, in close proximity to, and in connection with, an existing shaft there, the top of which at the surface of the ground was already 100 feet above the sewer, so that the total height would be 200 feet. This would act as a powerful ventilator, and it was part of the design to fix a small steam-engine, and an exhausting fan at the foot of the upper shaft and in connection with the lower one. Provision was also made to apply a furnace experimentally. That spot had been chosen because it was at a distance from any inhabited houses. Mr. Aird had suggested the desirability of putting in pipes and getting houses through which to carry ventilators; but it was extremely difficult to obtain sites for such a purpose. Not only the owners of the houses, but the whole neighbourhood would object. He hoped the time would come when a shaft would be placed at the eastern extremity of the sewer. He desired to bear his testimony to the admirable manner in which the work had been carried out by the Messrs. Aird, notwithstanding the many difficulties with which they had to contend. They had been the contractors for laying the central outfall pipe, in regard to which they displayed similar perseverance. A length of 1,500 feet of the pipes was below the lowest low-water mark. The pipes were put together with lead joints, and floated out in lengths of from 150 feet to 300 feet, the joints at the end of each section being made with wooden wedges, and the whole secured by screw piles. They were perfectly tight, and delivered the sewage admirably. He was still inclined to think that, for a town situated like Brighton, the system of pipe outfalls taken into deep water was a good one,

but, unfortunately, in this instance they were placed within sight where they were subject to prejudice. If they had been taken a mile from the town, and well out to sea, he believed they would have suited extremely well.

Mr. Grant said it had occurred to him that it might have been possible to combine the system recommended by Mr. Hawksley of extending the outlet pipes into the sea, with that adopted by Sir John Hawkshaw. He thought it might have been advantageous to use the old outfalls for carrying off the surface water as far as possible. It was of course very difficult to carry off separately every drop of surface water, but a large amount might have been taken into the sea by means of the old outfalls. Had this been done, much of the deposit, consisting of flints and sand, road metal and mud, which now found its way into the deep sewer, would have been kept out of it, and the expense which it entailed would have been saved. He would also suggest, with great deference, after the consideration given to the subject by Sir John Hawkshaw, that the sewer might have been improved by giving it less fall, say 2 feet instead of 3 feet per mile, and keeping the outfall 7 feet higher. The difference of discharge could easily have been made up by the slight increase of about 6 inches in diameter; and by raising the outfall it could have been kept clear about four hours out of the twelve. That opinion was based upon what might be observed of the two outfalls of the metropolitan drainage, at Barking and at Crossness. The three culverts forming the outfall sewer from Abbey Mills to Barking were kept on a high level, and had at all times a clear discharge into the reservoir. With regard to the sewer on the opposite side, it was exceedingly difficult to keep the lower length of 3 miles of it clear; as soon as it was cleansed it began to get foul again, because the outlet was periodically checked—the sewage flowed down into ponded-up deep water, so that there was a great tendency to deposit, with which it was difficult to deal. With reference to flushing, it was suggested in the Paper, that for the upper part of the sewer it might be necessary to get water from a company. It would be easy, however, to get sufficient water for flushing by fixing one or more penstocks or movable dams, to collect the drainage water behind them, and to let it off when required. These would be useful when it was necessary to examine or cleanse any section of the sewer, or to connect new drains or branch sewers. They would, however, cost much more than if they had been put in during the progress of the work. It appeared that the brickwork was estimated, and to a considerable extent carried out, at a

thickness of 9 inches, which he thought too little. With that thickness there could be but one collar joint, and there was great difficulty in keeping the water outside the culvert from getting into it. Reference had been made to 13½-inch work, which should as a rule be actually 14-inch; the difference being made up by two thick collar joints. He had seen some of the bricks used for this work; two of the kind mentioned in the Paper were very hard, and of one he had used a large number. The plan adopted in the main sewers of London of putting Staffordshire blue bricks in the invert was a good one, and quite justified the slight additional expense. Flushing had a great tendency to wear out the invert if a hard brick was not used. In London, also, there were chemical works discharging matters into the sewer that affected the brick-work; so that a strong brick like the Staffordshire blue was preferable on that account. Many years ago, wherever the ground was wet, an attempt was made to get over the difficulty by using brick blocks; but for the last fifteen years he had given up their use because it was an essential point to previously drain the trench thoroughly. A good foundation of concrete was made, and on this the brickwork was laid as securely and as dry as if above ground, every brick being properly jointed, which could not be done with brick blocks. With a straight joint it was impossible to bond in the work properly, and if there was water round the culvert, it was sure to get in at those large ill-jointed places. It appeared that radial bricks had been thought of, but not used. Twenty-five years ago he had specified radial bricks, but, fortunately, did not get them. He did not think they were of much use. They were more costly than the others by 25 per cent.; and if one face were injured the brick was of no use for any other purpose. In the next place, the joints, though thicker at the back, were as good, with cement, as the thinner joint of the radial brick, or even better. The method stated by the Author, of laying out the curves in the tunnel, was ingenious, and no doubt answered well. There were, however, simpler modes than that which Mr. Gamble had described. As a record of work done, the Paper was a useful one; and he only wished that it had dealt more with the principles of drainage, so as to afford room for a good debate upon the general subject of the sewerage and drainage of towns.

Mr. Hanvey observed that the question of outfall sewers upon the shore at Dover had been a vexed one for the last twenty years. A bay was formed by the Shakespeare Cliff, and the Admiralty Pier, with Archley Fort almost in the centre, where the outlet

pipe, 2 feet 6 inches in diameter, discharged. The result was that for a considerable period there was slack water, a quantity of sludge was deposited, and flocculent matter was seen floating about. This passed on towards the pier, and remained there until a north-easter, or some other powerful agent, carried it away. Efforts had been made for many years to get rid of the nuisance. Some persons thought the best mode would be to lay a pipe to the end of the Admiralty Pier, while others considered the pipes should be extended into a depth of 7 fathoms. He had himself made experiments with corks, at different times of the tide, which in about a quarter of an hour returned to the bathing machines on the Marine Parade. He also put in some corks in front of Archley Fort, and in about the same time they were on shore. There was a south-west breeze for about nine months in the year, which carried any floating matter in towards the shore. In quiet seasons the matter suspended in the water was precipitated, with what result might be easily imagined. He devised a scheme of carrying out the sewage by an intercepting sewer from Archley Fort to the end of the Shakespeare Cliff, and there discharging it. Mr. Harrison, the Government Inspector, came down and approved of the method; but the people were not satisfied. Sir John Hawkshaw was then called in, who also approved of the scheme of carrying the sewage to the west of the Shakespeare Cliff; but the people would do nothing until Government compelled them. With regard to ventilation, he believed that the greater the number of openings the better. He disapproved of ventilating by pipes through houses, or by shafts at intervals; the friction upon the pipes would altogether prevent their efficiency. There should be as many openings as possible; and, in order to prevent their being offensive, charcoal filters should be employed. The great thing was to take care that there was no internal communication with the private drainage. He should be glad to know the quantity of water pumped at Brighton, and the cost. At Dover about 50,000 gallons an hour were pumped without exhausting the adits, and they were only 220 yards long.

Mr. Haywood asked whether much spring water leaked into the intercepting sewer at Brighton.

Mr. Hayter in replying, in the absence of Sir John Hawkshaw and Mr. Gamble, said he would confine himself to answering the questions that had been asked. With regard to the A B C process, it had not been tried at Brighton. Some samples of the sewage had been sent to the Phosphate Sewage Company who worked the

process, but they said it was too diluted to be dealt with. The level of the sewer, at the extreme end of the outfall pipes, was at zero, or low-water ordinary spring tides, and the sewer rose 2 feet to the penstock, which was situated a short distance from the pipes; so that at low-water spring tides the sewer was entirely emptied, and at low-water neap tides nearly so. Mr. Homersham had stated that in tunnelling through chalk he had experienced no difficulty in shutting out a large quantity of water without pumping, filling the fissures with dry deal wedges. That method had been tried at Brighton, also thrusting cement bags into the fissures, and other expedients, but none of them would answer. The chalk was of a very friable character, and as soon as a fissure was stopped by a wedge or by cement bags, the water appeared in half-a-dozen other places. The only way of dealing with the water was to convey it away as it appeared by the pipes laid under the invert of the sewer, and pump it out. The quantity of sewage amounted to somewhat under 25 gallons per head of the population in twenty-four hours. In the daytime, when there was no rain, the ordinary depth of sewage was 12 inches, and the maximum velocity 84 feet per minute, or nearly 1 mile an hour. At night the flow was about 6 inches deep at the Chain Pier, and 10 inches at Portobello. The reservoir capacity of the sewer was sufficient to contain a rainfall of about $\frac{1}{8}$ inch during the comparatively short period when there was little or no discharge. The storm overflows had been in operation six times since the sewage was admitted in May 1874—that was to say, three times in 1874, and three times in 1875. On one of these occasions (the 4th of October, 1874) the rainfall had been 1·39 inch in twenty-four hours, of which 0·6 inch fell between nine and half-past ten in the morning. The quantity of silt removed from the catch-pits varied from six loads to twenty-one loads per week, the total quantity in seventy-five weeks (from July 1874 to December 1875) having been seven hundred and forty loads, or a little less than ten loads per week on the average. A load was little more than 1 cubic yard. The silt from the catch-pits was removed at night. Respecting the arrangements for flushing the inlet from the sea at the Steyne, the sea water was admitted at spring tides for four or five days in succession. Besides this, the upper end of the sewer was flushed by penning back the sewage by a sluice, but fresh water from the waterworks was now used, and by this means the upper end of the sewer was flushed twice a week, or oftener if there was no rain.

The area of the grate of the furnace now being erected, 1 mile

to the eastward of Kemp Town, was to be 20 square feet, the height of the chimney 100 feet, and the area of the top of the chimney 10 square feet. A valve would be introduced in the sewer to shut out the gases from the lower end. The site was selected because the Sewers Board had land there, and the spot was distant from houses, there being, in fact, no house within view, and because it was generally suitable. At one time there had been considerable leakage into the sewer, but before the sewage was let in, the joints from which water flowed were scraped out, caulked with yarn and tallow, and stopped with Portland cement. This plan had answered, and there was now but little leakage. It had been stated that, in a sanitary point of view, Brighton was no better off with the intercepting sewer than formerly. Before the new work had been determined upon, Sir John Hawkshaw told the Brighton authorities that sewage delivered into the ocean, from 1,500 to 2,000 feet from the shore, was not likely to be productive of disease or to be objectionable, diluted as it must be with a large volume of sea water. But that was not the only question. The specific gravity of sewage being less than that of sea water, the sewage rose to the surface; and even at the old central outfall at the Steyne, which was 1,760 feet from the shore and farther to seaward than any of the others, the stream of sewage was plainly visible from the shore, and to those who went in boats and came near the point of discharge the effluvium was unpleasantly evident. Moreover, the very appearance of large sewage pipes inspired feelings of disgust. Influenced by these considerations, the Brighton authorities determined, after protracted discussions and investigations, to discharge the sewage at a distance from the town, and the result proved that they had arrived at a right conclusion.

Mr. G. R. Stephenson, Vice-President, remarked that Mr. Gamble ought to be highly gratified at the reception of his Paper, and at the discussion which had followed it. He was rather surprised, however, that one point had not been fully brought before the Institution. He was not satisfied as to the way in which the gas emanating from the sewers had been dealt with.

December 14, 1875.

GEORGE ROBERT STEPHENSON, Vice-President,
in the Chair.

The discussion upon the Paper, No. 1,449, on "The Brighton Intercepting and Outfall Sewers," by Mr. JOHN GEORGE GAMBLE, occupied the whole evening.

ANNUAL GENERAL MEETING.

December 21, 1875.

THOS. E. HARRISON, President,
in the Chair.

The list of members nominated as suitable to fill the several offices in the Council was read.

Messrs. C. Frewer, R. H. Hill, C. E. Hollingsworth, Rob. C. May, W. Shield, T. M. Smith, F. Stevenson, Joseph Taylor, J. J. Wallis, and A. Williams were requested to act as Scrutineers of the Ballot, for the election of the President, Vice-Presidents, and other Members and Associates of Council for the ensuing year; and it was resolved that the Ballot Papers should be sent for examination every quarter of an hour that the Ballot remained open.

The Ballot having been declared open, the Annual Report of the Council, on the Proceedings of the Institution during the past year, was read. (*Vide* page 228.)

Resolved,—That the Report of the Council be received and approved, that it be referred to the Council to be arranged for printing, and that it be circulated with the Minutes of Proceedings in the usual manner.

Resolved,—That the thanks of the Institution are due, and are presented to Messrs. John Thornhill Harrison and Charles Frewer, for the comprehensive statement of Receipts and Payments they have prepared; and that Messrs. Charles Frewer and William Henry Barry be requested to act as Auditors for the ensuing year.

Mr. Frewer returned thanks.

The Telford and Watt Medals, the Telford and Manby Premiums, and the Miller Prizes, which had been awarded, were presented. (*Vide* pages 244 and 245.)

Resolved,—That the thanks of the Institution are justly due, and are presented to the Vice-Presidents and other members of the Council, for their co-operation with the President, their constant attendance at the Meetings, and their zeal on behalf of the Institution.

Mr. Stephenson, Vice-President, returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Harrison, President, for his persevering endeavours in the interests of the Institution, for his unremitting attention to the duties of his office, and for the urbanity he has at all times displayed in the Chair.

Mr. Harrison, President, returned thanks.

Resolved,—That the best thanks of the Meeting be given to Mr. Charles Manby, the Honorary Secretary, and to Mr. James Forrest, the Secretary, for their zealous and valuable services on behalf of the Institution and of the profession.

Mr. Forrest returned thanks.

The Ballot having been open more than an hour, the Scrutineers, after examining the papers, announced that the following gentlemen were duly elected:—

President.

GEORGE ROBERT STEPHENSON.

Vice-Presidents.

James Abernethy.	William Henry Barlow, F.R.S.
Sir W. G. Armstrong, C.B., F.R.S.	John Frederic Bateman, F.R.S.

OTHER MEMBERS OF COUNCIL.

Members.

Sir Joseph Wm. Bazalgette, C.B.	Sir John Coode.
Isaac Lowthian Bell, M.P., F.R.S.	Harrison Hayter.
George Berkley.	William Pole, F.R.S.
Fred. Jos. Bramwell, F.R.S.	Charles William Siemens, F.R.S.
George Barclay Bruce.	Sir Jos. Whitworth, Bart., F.R.S.
James Brunlees.	Edward Woods.

Associates.

Thomas Brassey, M.P. Douglas Galton, C.B., F.R.S.
Joseph Whitwell Pease, M.P.

Resolved,—That the thanks of the Meeting be given to Messrs. Frewer, Hill, Hollingsworth, May, Shield, Smith, Stevenson, Taylor, Wallis, and Williams, the Scrutineers, for the promptitude and efficiency with which they have performed the duties of their office; and that the Ballot Papers be destroyed.

[ANNUAL REPORT.

ANNUAL REPORT.

SESSION 1875-76.

THE Council have pleasure in congratulating the Institution upon a year of marked progress, not only in its home connections, but also, and especially, in its foreign relations. Well known as this Society has been in the United Kingdom and her dependencies as an active and enterprising body, recent policy has succeeded in establishing for it what may be fairly considered a cosmopolitan character.

In fact, the Institution is gradually becoming the recognised medium of communication between engineers of different nations. This intercourse is stimulated by the visits paid by foreign engineers to this country for the purpose of inspecting public works. In granting, through the Secretary, letters of introduction to those in charge of engineering operations of an interesting character, the Council feel sure they consult the wishes of the members; and in acknowledging the courtesy accorded to these introductions, they would refer to the unfailing urbanity with which such attentions are reciprocated in the case of British engineers travelling on the Continent and in the United States.

THE ORDINARY MEETINGS.

Fifteen Papers, on nine subjects, were read and discussed at the twenty-three Ordinary Meetings during the past session. Seven nights were devoted to matters involved in the construction and working of railways; three evenings were taken up in considering the water supply of English towns, and two in reviewing the Indian system of water supply and of tanks; the manufacture of steel, and the design and construction of gasworks were each debated at three meetings; the Chesil Bank occupied two evenings, while docks, breakwaters, and heavy guns had one night each.

One hundred and seventeen persons joined in the discussions, of whom ninety-one belonged to the Institution and twenty-six

were visitors. The average attendance at the meetings was 227, as compared with 232 in the previous session, the slight falling-off being on the part of the visitors.

The Publications.

The communications and discussions referred to, with the two new sections of "Other Selected Papers," and "Abstracts of Papers in Foreign Transactions and Periodicals," now published for the first time, in pursuance of the promise made last year, are recorded in four volumes of Minutes of Proceedings, vols. xxxix. to xlii., together 1,599 pages of printed matter, illustrated by 39 plates and 83 woodcuts. The largest previous amount was for the session 1869–70, when the two volumes contained 1,003 pages of printed matter, 37 plates, and 62 woodcuts.

The second section of the Minutes, comprising fifteen Selected Papers, includes those essays which have been submitted for the approval of the Council, and were considered of sufficient importance to be printed, without being read and discussed. These Papers treat of subjects of a very varied nature. Sweden, India, France, Canada, the United States, Holland, Russia, England, and Switzerland are represented. In Russia two distant points of the Empire, St. Petersburg and the Black Sea, offer topics for description. The two great difficulties with which Holland has to contend—the bridging of its vast rivers and the securing of its treacherous foundations—are dealt with. The use of dynamite for blasting rock under water, the strength of Portland cement, the employment of petroleum and other mineral oils for the manufacture of gas,—questions of practical importance,—and a study on the curves of equilibrium for rigid arches, which belongs to the domain of theory, complete this section of the Proceedings.

To the Authors of some of these communications Premiums have been awarded as follows:—Telford Medals and Premiums to William Hackney, Harry Edward Jones, Alexander Richardson Binnie, and George Frederick Deacon; a Watt Medal and the Manby Premium to John Clarke Hawkshaw; and Telford Premiums to Jules Gaudard, Professor Joseph Prestwich, Josiah Timmis Smith, Charles Colson, and Thomas Colclough Watson.

The other entirely new feature in the Minutes—the abstracts of the most important articles on Engineering in foreign journals—involved much thought and labour on the part of the Council, whose anticipations, however, as to their value have been fully realised. The successive numbers of more than 100 different periodicals have been regularly examined, and from 63 of these

periodicals articles have been selected. Among the sources of information 22 are French, 12 Prussian, and 8 Austrian; Bavaria, America, and Italy contribute three each; Russia, Holland, and Belgium, two each; India, Spain, Portugal, Saxony, Sweden, and Switzerland, one each. In the four volumes there are 237 abstracts, amounting in the aggregate to 481 pages, or an average of 2 pages for each. The number of abstractors engaged in this work has been forty-six.

In selecting the Papers care was taken to obtain as great a variety of subjects as possible, in all branches of Engineering, and in allied experimental sciences. It is not, however, unusual to find the literature of one period mainly dealing with the same question, discussing quite independently similar views or kindred matters. If there should seem, therefore, to be in any one series a preponderance of articles on one or two branches of engineering, it should be borne in mind that the next series will probably contain as great a preponderance in other branches, and so equalise them in the end. It has been attempted to arrange the articles systematically, and although it has not been easy to bring each under a definite heading, inasmuch as sometimes a single abstract treats of matters belonging to several branches of Engineering, the system is believed to be good, and it will be continued. Telegraphy, electricity, and magnetism have received a considerable share of attention, as the researches on these subjects both in France and in Germany have been of great value.

Each series of Abstracts has been issued separately, and copies have been forwarded to the Authors of the various Papers, to the editors of scientific periodicals abroad, to the public bodies and societies connected with engineering, and to many engineers of note. The reception these communications have met with has everywhere been most flattering and encouraging. Monsieur H. Resal publicly announced at a sitting of the French Academy the receipt of these Abstracts, and was pleased to add some complimentary remarks; and several of the Abstracts have been translated and reprinted abroad. Many letters have also been received from the Authors of the abstracted articles, containing expressions of gratification at having their writings brought to the knowledge of English engineers; and some have already sent reprints of their Memoirs for the use of the Library, accompanied in several cases with carefully prepared Abstracts for the Minutes of Proceedings.

To make the record of foreign engineering literature as complete

as circumstances will allow, it is intended to give, in an early volume, a catalogue of the articles on engineering and kindred subjects that have appeared in the most important periodicals during the year 1875. Those articles which have been abstracted will be indicated, and members will therefore have an opportunity of judging how far the selection has been comprehensive and complete.

The Supplemental Meetings.

Twelve supplemental meetings were held exclusively for the reading and discussion of Papers by Students, at which a Vice-President or a Member of Council generally presided. Although none of the communications submitted were deemed worthy of the Miller Scholarship, seven of them were considered deserving of Miller Prizes. The average attendance at these meetings was twenty-four; the number taking advantage of them was seventy-four out of a total of about three hundred Students, and only one Student was present at all the meetings. Although the Papers were of the usual character, the Council regret that the discussions were not equal to those of some previous years.

Miller Prizes have been awarded to Arthur Ernest Baldwin, James Charles Inglis, William Beswick Myers, Arthur Spence Moss, William Patterson Orchard, Joseph Tysoe, and John Charles Mackay.

Presents, etc.

Among the presents received during the past twelve months mention must be especially made of a portrait, by Mr. Charles Landseer, *R.A.*, of our deceased Past-President, Mr. John Robinson M'Clean, *M.P.*, *F.R.S.*, the gift of his son, Mr. Frank M'Clean, M. Inst. C.E. Also of two original oil sketches, by the late Mr. John Lucas, for which you are indebted to Mr. Rawlinson, *C.B.*, M. Inst. C.E.—one, of the residence of Mr. George Stephenson at Killingworth Colliery, for a picture painted in 1860; the other, of the Britannia Bridge, forming the background for the portrait of the late Mr. Robert Stephenson, *M.P.*, Past-President Inst. C.E.; and likewise of a painting, by Scott, "Old Westminster Bridge," the gift of Mr. Price Williams, M. Inst. C.E. The Council have purchased for the Institution the portrait of Mr. Robert Stephenson, which Mr. Lucas painted for the Britannia Bridge picture.

The Roll of the Institution.

That part of the Annual Report which records the growth in the number of members, though necessarily consisting of dry figures, bears witness to facts that must be regarded with satisfaction. The Institution has long since emerged from the struggling condition which characterised the first half of its existence; but its recent progress has surpassed anything that could have been anticipated, from a consideration of the small and fluctuating additions of twenty or thirty years ago. The average effective increase for the six years ending 1850 was 22; for the past six years it has been 112, while for the year 1874–75 it was 155, the highest yet attained.[1] The total number of members of all classes (irrespective of the Students) on the books on the 30th of November last was 2,284. Naturally, the larger portion is resident in the United Kingdom; but between five and six hundred practise the profession in the colonies and in foreign countries—nearly one-half of these being in India, and the other moiety so thoroughly dispersed that there is no country but shelters several representatives of this Institution.

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[1] The tabular statement for the years 1873-74 and 1874-75, of the transfers, elections, deceases, resignations, and erasures of the members of all classes belonging to the Corporation, that is, exclusive of the Students, is as follows:—

Year.	Honorary Members.	Members.	Associates.	
1873-74.				
Transferred to Members	..	..	23	
Elections	..	23	165	189 − 54 = 135
Restored to Register	..	..	1	
Deaths	..	19	21	
Resignations	..	1	7	54
Erased from Register	..	1	5	
Members of all Classes on the Books, 30th November, 1874	15	791	1,323	2,129
1874-75.				
Transferred to Members	..	..	17	
Elections	3	33	176	212 − 57 = 155
Deaths	4	15	22	
Resignations	..	2	6	57
Erased from Register	..	1	7	
Members of all Classes on the Books, 30th November, 1875	14	823	1,447	2,284

There have been three elections into the class of Honorary Member. These include one German philosopher, Professor Dr. Clausius, whose profound researches respecting the dynamical theory of heat, and the application of that theory to the production of motion, have borne fruit in many of the mechanical achievements of this century; one French savant, General Morin, whose elaborate investigations in various branches of mechanics have greatly advanced the application of pure science to practical purposes, particularly to those which come within the province of the engineer; and one English experimental philosopher, Sir Charles Wheatstone—since unfortunately deceased—whose numerous discoveries and inventions in acoustics, optics, electricity and magnetism, and whose successful development of the electric telegraph, established for him a world-wide reputation.

The following are the deceases announced during the past year, the bracketed figures after some of the names referring to the volumes of Proceedings in which memoirs have already been printed:—

HONORARY MEMBERS: Baron Charles Dupin (xl., 242), General Tscheffkine, Sir Charles Wheatstone, *F.R.S.*, and the Rev. Professor Robert Willis, *M.A.*, *F.R.S.* (xli., 206).

MEMBERS: Charles Atherton (xlii., 252), Price Prichard Baly, Edward Bell (xlii., 255), Jabez Church (xli., 211), James Collins (xlii., 257), Thomas Dale (xli., 212), James Dees, Thomas Emerson Forster, George James Hervey Glinn (xli., 216), Thomas Hardinge Going, George Harrison, Charles William Hawkins (xlii., 258), Thomas Lloyd, *C.B.* (xli., 217), Charles Innes Spencer, and Charles Blacker Vignoles, *F.R.S.*

ASSOCIATES: Edward Adams (xli., 221), Robert Dudley Baxter (xlii., 259), Thomas Bell (xlii., 261), Augustus Beaty Bradbury, George Cæsar Cooke, Edward Gershom Davenport, *M.P.* (xli., 225), Robert Hannay (xl., 261), Jesse Hildred, Andrew Cassels Howden (xlii., 263), Captain William Innes, *R.E.*, Thomas Jackson, Jun., Joshua Llewellin Morgan, Philip Algernon Herbert Noyes, Robert Ogilvie (xlii., 263), John Parson (xli., 227), Frederick Peck, James Allen Ransome (xli., 228), William Rawlinson, Frederick William Taylor, George Taylor, (xlii., 265), Henry Robert Woolbert (xlii., 265), and George Edward Wythes (xli., 232).

The deceased Honorary Members were all men of high distinction; and among the Members was your esteemed and revered Past-President, Mr. Vignoles, who, for nearly half a century, maintained the honour and reputation of the Institution.

The names of Robert Brodie and William Henry Coddington,

MEMBERS; and Charles Dallas Alexander, John Cameron, John Dalrymple, Thomas Donkin, Captain Robert Robertson, *R.N.*, and Clarence Edward Trotter, ASSOCIATES, have been removed from the list in compliance with the written letters of resignation received from the respective parties.

CLASSIFICATION OF MEMBERS AND ASSOCIATES.

In the last Report mention was made of a feeling of dissatisfaction that had been manifested with the present definition of the class of Associates; and the Council expressed the opinion, that it was "open for consideration whether some modification could not be devised which, while retaining an honourable distinction for the more experienced members, would yet afford a just recognition of the position of their younger brethren."

The Council have, during the past year, devoted much and careful attention to this subject, and have arrived at the conclusion that it is desirable to create a new class, in order to distinguish between those who are engaged in the active pursuit of the profession of Civil Engineering, and those who are not so engaged; but as the mode in which this alteration should be carried out is found to involve some technical questions, it has not been possible as yet to prepare a definite recommendation. The question is one, however, which cannot fail to occupy the immediate consideration of the incoming Council.

THE STUDENTS ATTACHED TO THE INSTITUTION.

The number of candidates admitted by the Council last session as Students was 89. On the other hand, 22 Students were elected Associates, 19 resigned, 4 were erased from the register, and 2 died. The effective increase was thus 46, making the total number 324, although the class has only been in existence eight years. Large accessions have proceeded from the Royal Indian Engineering College, each candidate being nominated either by the Director or by one of the Professors of the College belonging to the Institution. It has not yet been considered feasible to make any alterations in the rules respecting this class, in the direction of exacting from the candidates a special scientific education; but the matter continues to receive the attention of the Council.

FINANCE.

The statement of receipts and payments (as certified by the auditors) shows that on the credit side of the account the income proper (inclusive of the repayment of a sum of £12 8*s*. 1*d*. expended for

the Benevolent Fund in 1874) was £8,053 8*s*. 11*d*.; the admission fees, &c. (required by the Bye-Laws to be added to capital), amounted to £2,114 3*s*. 6*d*.; while the Trust Funds produced £456 6*s*.: together, £10,623 18*s*. 5*d*. On the other hand, on the debit side of the account, the general expenditure (after giving credit for sums representing donations to the Library) reached £4,917 3*s*. 10*d*.; and the disbursements for Minutes of Proceedings, after deducting the contributions to the Publication Fund, and the amount paid for transactions, was £3,101 17*s*. 4*d*.: together, £8,019 1*s*. 2*d*., or very nearly equal to the income. To this last-named amount must be added, to effect a balance of the receipts from all sources, the investment on capital, £2,078 6*s*. 4*d*.; the payments for premiums under trust, £277 4*s*. 7*d*.; and the repayments of dividends unexpended in 1874 on the Telford and the Miller Funds, £229 3*s*.; while there is owing from the Benevolent Fund for disbursements in 1875, £11 4*s*. 8*d*., and the cash at the bankers is £8 18*s*. 8*d*. in excess of what it was on the 30th of November, 1874. It also appears, that there is due to capital, £35 17*s*. 2*d*.; to the Telford Fund, £24 5*s*. 6*d*.; to the Miller Fund, £118 19*s*. 3*d*., and to the Howard Fund, £16 8*s*. 4*d*. (to which last-named sum must be added the dividends of the two previous years, viz., £32 13*s*. 9*d*.). Of the income there is an apparent unexpended balance of £34 7*s*. 9*d*., but the liabilities have not been so fully met as they were twelve months ago, as the printer and the engraver have not been paid for the two volumes of Minutes of Proceedings last issued. The enlargement of the publications has necessarily involved a much greater outlay; but the Council see no reason to doubt that the publications can be continued on the same scale as in the past year, without exceeding the annual revenue.

Investments.

In accordance with the recognised practice of late years, the amounts derived from Life Compositions, and the Entrance and Building Fund Fees of new members, are considered as capital, and are invested in the name of "The Corporation of the Institution of Civil Engineers." The sum so dealt with in the year under review was, as already stated, £2,078 6*s*. 4*d*.; and with this was purchased £1,882 Manchester, Sheffield, and Lincolnshire Railway Company's Four and a half per cent. Debenture Stock. In conformity with the opinion of counsel, obtained some time back, the accumulations of dividends on the Trust Funds are placed from year to year in Government securities. The balance

of interest received during 1874 on account of the Telford and the Miller Funds has thus been added to the capital of those funds, the amounts being respectively £114 8*s.* 2*d.* and £114 14*s.* 10*d.*, represented by £123 3*s.* 8*d.* and £123 10*s.* 10*d.* Reduced Three per Cents. The total of the investments of the year has therefore been £2,307 9*s.* 4*d.*, as against £2,997 10*s.* 11*d.* in 1874.

The Funds.

From the Abstract of Receipts and Expenditure, it will be seen that the funds now belonging to, or under the charge of, the Corporation—the details of which are given—are as follows:—

	£.	*s.*	*d.*
Institution Investments	20,876	1	8
Trust Funds.	14,171	0	6
Total nominal or par value . . .	35,047	2	2
Cash in the hands of the Treasurer	250	13	6
Together amounting to	£35,297	15	8

as compared with £33,158 13*s.* 4*d.* at the date of the last Report. Of these funds, a sum of £12,115 2*s.* 2*d.* is placed in Government securities, and £22,932 stands, in nearly equal proportions, in guaranteed stocks of seven of the principal railway companies. The investments yield an average rate of interest of 3¾ per cent. The certificates have been inspected by the auditors, who have also obtained from the different railway companies acknowledgments that the Corporation is the registered proprietor of the several amounts of stock.

Balloting List for Council.

It will have been noticed that the name of Mr. Hemans, the senior Vice-President in duration of office, has this year been omitted from the balloting list for Council. This was done at the request of Mr. Hemans himself, who desired, on account of the state of his health, that he might not be put in nomination, in accordance with the Bye-Laws, for the office of President. On receiving this intimation, the Council unanimously recorded their sense of the services of Mr. Hemans in the following terms:—

"Resolved,—That the Council hear, with the deepest possible regret, of the continued indisposition of their esteemed colleague Mr. Hemans.

"That, having regard to the marked attention Mr. Hemans

invariably showed, and the deep interest he uniformly took, in all the details of the administration of the Society, the Council had looked forward with satisfaction to the period, now approaching, when Mr. Hemans might have been elected President, the duties of which office, they feel assured, would have been discharged with honour and credit to himself, and with signal advantage to the Institution.

"That, in receiving his resignation, the Council desire to record how deeply they deplore the temporary loss of Mr. Hemans' distinguished services; and how earnestly they hope that at no distant date he may be restored to health, and be enabled to assume the highest office the profession has the power to bestow."

The Honorary Secretary.

The Report laid before the members must be regarded as highly satisfactory. It is believed that the Council now going out of office, as well as their predecessors, have done their best to promote the prosperity of the Institution; but without efficient aid, their labours would have been, if not frustrated, at all events rendered difficult. The Institution is happy in having most efficient officers, none more so than their Secretary, and their Honorary Secretary, Mr. Manby. The Council think this a fitting opportunity to announce the fact that, before the next Annual Meeting, the Institution will have had the benefit of twenty years' gratuitous service from the Honorary Secretary; and they trust that the members will concur with them in expressing sincere acknowledgments to Mr. Manby for the valuable services which he has rendered to the Institution and to the profession at large.

Conclusion.

The works of engineers have raised what was formerly a craft to a distinct and recognised profession. The civil engineer has to apply the results arrived at by the mathematician, the physicist, the chemist, and the geologist; to be, as far as possible, a combination of the man of science and the workman; and to carry into practice the results of scientific research and discovery—results which are ever varying and widening as the domain of knowledge extends. When the duties and responsibilities of engineers are considered, the necessity of embracing every opportunity for furthering professional knowledge will be apparent, and no better means than such an organisation as that afforded

by this Institution could be devised. During the time the Institution has been in existence the wealth of the world has been largely developed, mainly by the facilities of intercommunication by railways, harbours, and ocean steam-ships, by telegraphs, and by improvements in machinery—most of which are due to the members of this Association. These inventions have tended to promote personal intercourse between the peoples of different nations, have fostered material and intellectual progress, and have increased the comfort and the welfare of all classes of society.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

£.	s.	d.	*Dr.*	£.	s.	d.	£.	s.	d.
			To Balance in the hands of the Treasurer				241	14	10
			— Subscriptions and Fees:—						
			Arrears	249	18	0			
			Current	6,962	6	0			
			Advance	45	3	0			
			Life Compositions	437	6	6			
			Fees	655	4	0			
							8 349	17	6
			— Building Fund				1,021	13	0
			— Publication Fund				210	16	6
			— Library Fund				79	2	6
			— Publications :—Sale of Transactions				219	15	2
			— Deposit Interest				31	3	10
			— Dividends: 1 year on						
			Telford Fund.						
2,839	10	10	Three per Cent. Consols	84	9	6			
2,586	0	11	Three per Cent. Reduced . .	76	18	8			
2,377	10	5	Three per Cent. Consols (Unexpended Dividends) . .	70	14	8			
816	1	3	Three per Cent Reduced (Ditto, ditto)	24	5	6			
							256	8	4
			Manby Donation.						
200	0	0	Great Eastern Railway Co., Norfolk, Five per Cent. Preference Stock	..			9	18	4
			Miller Fund.						
2,000	0	0	Lancashire and Yorkshire Railway Four per Cent. Debenture Stock	79	6	8			
1,100	0	0	Great Eastern Ditto	43	12	8			
582	18	6	Three per Cent. Consols (Unexpended Dividends) . . .	17	6	10			
1,117	4	1	Three per Cent. Reduced (Ditto, ditto)	33	4	10			
							173	11	0
			Howard Bequest.						
551	14	6	New Three per Cents . . .	..			16	8	4
			Institution Investments.						
3,650	0	0	Great Eastern Railway Four per Cent. Debenture Stock . .	144	15	8			
3,000	0	0	London and North Western Ditto	119	0	0			
1,500	0	0	London, Brighton, and South Coast Ditto	59	10	0			
3,000	0	0	North Eastern Ditto	119	0	0			
3,000	0	0	Great Northern Ditto . . .	119	0	0			
£28,321	0	6	Carried forward . .	£561	5	8	£10,610	9	4

from the 1st DEC., 1874, *to the* 30th NOV., 1875.

PAYMENTS.

Cr.	£. s. d.	£. s. d.
By Balance due to the Secretary		1 8 11
— House, Great George Street, for Rent, &c.:—		
Repairs	176 0 10	
Rent	652 17 4	
Rates and Taxes	63 11 5	
Insurance	30 6 6	
Furniture	282 13 1	
		1,205 9 2
— Salaries		1,650 0 0
— Clerks, Messengers, and Housekeeper		645 5 10
— Donation to late Housekeeper		30 0 0
— Postage and Parcels:—		
Postage	99 18 9	
Parcels	6 17 7	
		106 16 4
— Stationery, Engraving, Printing Cards, Circulars, &c.		314 3 2
— Light, Fuel, &c.:—		
Coal and coke	41 18 0	
Candles	0 2 4	
Oil	0 9 10	
Gas	62 3 11	
Water for Engine	7 8 0	
		112 2 1
— Tea and Coffee		30 10 6
— Library:—		
Books	328 19 9	
Periodicals	50 8 2	
Binding Books	202 7 11	
		581 15 10
— Publication, Minutes of Proceedings		3,532 9 0
— Telford Premiums		250 13 7
— Watt Medals		4 15 0
— Manby Premium		4 16 9
— Miller Prizes		60 0 3
— Diplomas		31 10 0
— Manuscripts, Original Papers, and Drawings		1 2 10
— Annual Dinner (Official Invitations, &c.)		147 15 7
— Winding and Repairing Clocks		1 10 0
— Incidental Expenses:—		
Christmas Gifts	1 16 6	
Assistance at Ordinary Meetings	10 19 0	
Ditto at Students' Meetings	4 15 0	
Beating Carpets and Sweeping Chimneys	1 6 2	
Household Utensils, Repairs, and Expenses	101 0 5	
		119 17 1
Carried forward		£8,832 1 11

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS—*cont.*

Dr.

£.	s.	d.		£.	s.	d.	£.	s.	d.
28,321	0	6	Brought forward . .	561	5	8	10,610	9	4
			To Dividends—*cont.*						
			Institution Investments: cont.						
1,000	0	0	Lancashire and Yorkshire Railway Debenture Stock . .	39	13	4			
1,500	0	0	London, Brighton, and South Coast Ditto, Four and a Half per Cent. Ditto . .	66	18	10			
1,000	0	0	Manchester and Sheffield Ditto	44	12	6			
1,882	0	0	Ditto—New Investment . .	0	0	0			
1,344	1	8	New Three per Cents . . .	39	19	8			
							752	10	0
£35,047	2	2	Total nominal or par value of Funds.				£11,362	19	4
			To Telford Fund, Repayment of Extra Cost of Binding, &c.	18	10	9			
			— Manby Premium, ditto, ditto	14	6	9			
			— Miller Prize, ditto, ditto	5	8	6			
							38	6	0
			— Benevolent Fund Petty Disbursements, 1874				12	8	1
							£11,413	13	5

from the 1st DEC., 1874, *to the* 30th NOV., 1875.

PAYMENTS—*cont.*

Cr.		£.	s.	d.
Brought forward		8,832	1	11
By Legal Expenses		12	4	0
		8,844	5	11
— Benevolent Fund Petty Disbursements, 1875		11	4	8
— Telford Fund.—Balance of Income not yet expended in Annual Premiums, invested in £123 3s. 8d., Three per Cent. Reduced	114 8 2			
— Miller Fund.—Ditto, £123 10s. 10d., ditto	114 14 10			
— Institution Investment:— £1,882, Manchester, Sheffield, and Lincolnshire Railway Four and a Half Per Cent. Debenture Stock	2,078 6 4			
		2,307	9	4
— Balance Nov. 30, 1875, in the hands of the Treasurer		250	13	6
		£11,413	13	5

Examined and found correct.

(Signed) JOHN THORNHILL HARRISON, CHARLES FREWER } *Auditors.*

JAMES FORREST, *Secretary.*

December 7th, 1875.

PREMIUMS AWARDED.

Session 1874–75.

The Council of The Institution of Civil Engineers have awarded the following Premiums:—

1. A Telford Medal, and a Telford Premium, to William Hackney, B.Sc., Assoc. Inst. C.E., for his Paper on "The Manufacture of Steel."

2. A Telford Medal, and a Telford Premium, to Harry Edward Jones, M. Inst. C.E., for his Paper on "The Construction of Gasworks."

3. A Telford Medal, and a Telford Premium, to Alexander Richardson Binnie, M. Inst. C.E., for his Paper on "The Nágpúr Waterworks, with Observations on the Rainfall, the Flow from the Ground, and Evaporation at Nágpúr; and on the Fluctuation of Rainfall in India and in other Places."

4. A Telford Medal, and a Telford Premium, to George Frederick Deacon, M. Inst. C.E., for his Paper "On the Systems of Constant and Intermittent Water Supply, and the Prevention of Waste, with special reference to the restoration of Constant Service in Liverpool."

5. A Telford Premium to Jules Gaudard, C.E., of Lausanne, for his "Notes on the Consolidation of Earthworks."

6. A Watt Medal, and the Manby Premium, to John Clarke Hawkshaw, M.A., M. Inst. C.E., for his Paper on "The Construction of the Albert Dock at Kingston-upon-Hull."

7. A Telford Premium to Professor Joseph Prestwich, M.A., F.R.S., Assoc. Inst. C.E., for his Paper "On the Origin of the Chesil Bank, and on the Relation of the existing Beaches to past Geological Changes independent of the present Coast Action."

8. A Telford Premium to Josiah Timmis Smith, M. Inst. C.E., for his Paper "On Bessemer Steel Rails."

9. A Telford Premium to Charles Colson, Assoc. Inst. C.E., for his "Details of the Working Tests and Observations on Portland Cement, made during the Construction of the Portsmouth Dockyard Extension Works."

10. A Telford Premium to Thomas Colclough Watson, M. Inst. C.E., for his "Description of the Use of Fascines in the Public Works of Holland."

THE COUNCIL have likewise awarded the following Prizes to Students of the Institution:—

1. A Miller Prize to Arthur Ernest Baldwin, Stud. Inst. C.E., for his Paper on "The Design and Construction of Lock Gates."

2. A Miller Prize to James Charles Inglis, Stud. Inst. C.E., for his Paper, "Experiments on Current Meters and their Bearing on the Hydraulics of Rivers."

3. A Miller Prize to William Beswick Myers, Stud. Inst. C.E., for his "Comparison of the various forms of Girder Bridges, showing the Advantages of the Schwedler Bridge; together with an elucidation of the Theoretical Principles of the same."

4. A Miller Prize to Arthur Spence Moss, Stud. Inst. C.E., for his Paper on "The River Humber."

5. A Miller Prize to William Patterson Orchard, Stud. Inst. C.E., for his Paper on "Hydraulic Calculations relating to Water Pressure and Walls to resist it, Gauging of Water, the Flow of Water in open Channels and in Pipes."

6. A Miller Prize to Joseph Tysoe, Stud. Inst. C.E., for his Paper on "The Manufacture of Illuminating Gas from Coal."

7. A Miller Prize to John Charles Mackay, Stud. Inst. C.E., for his Paper on "Concrete."

SUBJECTS FOR PAPERS.

Session 1875–76.

The Council of The Institution of Civil Engineers invite communications, of a complete and comprehensive character, on any of the Subjects included in the following list, as well as on other analogous questions. For approved Original Communications, the Council will be prepared to award Premiums, arising out of special Funds bequeathed for the purpose, the particulars of which are as under :—

1. The Telford Fund, given "in trust, the Interest to be expended in Annual Premiums, under the direction of the Council." This bequest (with accumulations of dividends) now produces nearly £260 annually.

2. The Manby Donation, given "to form a Fund for an Annual Premium or Premiums for Papers read at the meetings," of the value of £10 a year.

3. The Miller Fund, bequeathed by the testator "for the purpose of forming a Fund for providing Premiums or Prizes for the Students of the said Institution, upon the principle of the 'Telford Fund.'" This Fund (with accumulations of dividends) now realises about £170 per annum. Out of this Fund the Council have determined to establish a series of Scholarships,—to be called "The Miller Scholarships of the Institution of Civil Engineers,"—for Papers from Students, and to award one such Scholarship, not exceeding £40 in value, each year, and *tenable* for three years.

4. The Howard Bequest, directed by the testator to be applied "for the purpose of presenting periodically a Prize or Medal to the author of a treatise on any of the uses or properties of iron, or to the inventor of some new and valuable process relating thereto, such author or inventor being a Member, Graduate, or Associate of the said Institution." The annual income amounts to rather more than £16. It is proposed to award this prize every five years, commencing in 1877.

The Council will not, in any case, make an award unless a communication of adequate merit is received; but, on the other hand, more than one Premium will be given, if there are several deserving memoirs on the same subject. In the adjudication of the Premiums no distinction will be made between essays received from a Member, an Associate, or a Student of the Institution (except in the cases of the Miller and the Howard bequests, which are limited by the donors), or from any other person, whether a Native or a Foreigner.

LIST.

1. On the Flow of Fluids, liquid and gaseous.
2. On Portable Apparatus for Gauging the Materials, and for the Expeditious Mixing of large quantities, of Portland Cement Concrete.
3. On the Value and Strength of the different Materials used for making Concrete: with Experiments on the Proper Proportions of the various ingredients, and of the Water, whether salt or fresh, to produce the Strongest Mixture.
4. On the Application of Steam Machinery for Excavating, and the Cost as compared with Hand Labour.
5. On Stone-quarrying and Stone-working Machinery.
6. On the Manufacture of Cast and Wrought Iron and of Steel of various qualities; on the effect of the Admixture of Foreign Substances; and on the Experimental Tests by which the Quality may be ascertained.
7. On the Process of Forging by Steam Hammers and other Percussive Machinery, and by the Hydraulic Press.
8. On the Effects of Pressure on Cast Steel in the mould.
9. On the Results of Experience in the recent Extended Use of Steel in Mechanism and in works of Construction.
10. On the Alteration in the Condition of Metals caused by use or wear.
11. On the best Mode of Uniting Steel and other Metals employed in Construction and in Boiler Work, and on the Effect of the Operations of Punching, Drilling, and Riveting on such Metals.
12. On the Construction of Warehouses and other buildings for storing Goods, with the Special View of resisting Fire, and on the relative Merits of brickwork, iron, and timber for that object.
13. On the Construction of Street Tramways, the best means of adapting them for the conveyance of passengers and goods,

and of preventing injury and inconvenience to other carriages travelling on the same roads.

14. On Modern Methods of Constructing the Foundations of Bridges.
15. On the Design, generally, of Iron Bridges of very large span, for Railway traffic.
16. On the Comparative Merits of European and American Wrought-Iron Railway Bridges.
17. On Canal Locks, Inclined Planes, and other modes of overcoming differences of level on Canals.
18. On Dock Gates and Caissons, including a Description of the requisite external and internal arrangements, with recent practical examples.
19. On Percussive and other Rock Drills.
20. On the Appliances and Methods used for Tunnel-driving, Rock-boring, and Blasting, in this country and abroad, with details of the cost and of the results attained.
21. On Railway Rolling Stock Capacity in relation to the dead weight of the vehicles.
22. On the best mode of Testing Iron and Steel Rails for Railways.
23. On the Water Supply of Towns, including a description of the sources of supply, of the different modes of storing, collecting and filtering water, of the various incidental works, of the distribution to the consumers, and of the general practical results.
24. On the Constant Service of Water Supply, with special reference to its introduction into the Metropolis, in substitution for the Intermittent System.
25. On the various Modes of Dealing with Sewage, either for its disposal or its utilisation.
26. A History of any Fresh-Water Channel, Tidal River, or Estuary,—accompanied by plans and longitudinal and cross sections of the same, at various periods, showing the alterations in its condition,—including notices of any works that may have been executed upon it, and of the effect of the works.
27. On the relative Value of Upland and of Tidal Waters in maintaining rivers, estuaries and harbours.
28. On the different Systems of River and Canal Towage.
29. On Improvements in the Construction of Furnaces and on Combustion.
30. On the Construction of Steam Boilers adapted for very High Pressures.

31. On the best practical Use of Steam in Steam Engines, and on the effects of the various modes of producing Condensation.
32. On the Results of Experiments on Steam Jacketing.
33. On the Modern Construction of Marine Engines, having reference to Economy of the Working Expenses, by Superheating, Surface Condensation, High Pressure, great Expansion, &c.
34. On the Construction of Portable Steam Engines, or other Motors, of very light weight, suitable for light boats, aerial machines, &c.; and on Condensing with Air.
35. On the relative Cost of the Conveyance of Coal by Rail and by Steamer, and on the best mode of loading and unloading to diminish breakage.
36. On the various descriptions of Pumps employed for Raising Water or Sewage, and their relative efficiency.
37. On the employment of Wind or Water as a Motive Power, their relative advantages and disadvantages compared with Steam Power, and the Motors most suitable for utilising them in the best manner.
38. On the Use of Gas as a Motor.
39. On the best Methods of Removing Grain in bulk from a Ship to a Warehouse, for distributing in the Warehouse, and on the various modes in which grain is stored in bulk.
40. On the Manufacture of Mineral Oils, and the Lamps best adapted for their consumption in dwellings and lighthouses.
41. On the 'Output' of Coal in the United Kingdom, as compared with that of other countries, illustrated by statistical tables, plans, and diagrams, showing where Coal is produced, and where and how it is consumed.
42. On the Sinking to, and Machinery applied at, deep Coal Mines (in Saxony, for instance), with a notice of the modifications necessary in future Coal Mining Operations suggested (or indicated) by the working of deep sinkings.
43. On the Ventilation and Working of Railway Tunnels of great length.
44. On Compressed Air as a Motive Power, particularly as applied to Machinery in Mines and to Locomotives in Tunnels, with some account of its application on the Continent; and generally on the Methods of transmitting Force to distant points, including Details of the existing systems of Rope Transmission.
45. On the Dressing of the Ores of Lead, Copper, Zinc, and Tin, by any other process than that of Water, and on the

Smelting of such Ores, with details of the results and cost by different methods.

46. On the Washing of Small Coal, and the Manufacture of Coke and of Artificial Fuel.
47. On heavy and light Wood Working Machinery.
48. On Pneumatic Telegraphs, and on Pneumatic Despatch Tubes, designed with a view to economical working, and to the attainment of high speeds in long lengths of pipe.
49. On recent Progress in Telegraphy, including a notice of the theoretical and practical data on which that progress has been based; with some account of the improvements in the construction of land and sea lines and in the working instruments.

Instructions for Preparing Communications.

The Communications should be written in the impersonal pronoun, and be legibly transcribed on foolscap paper, on the one side only, leaving a sufficient margin on the left side, in order that the sheets may be bound. A concise abstract must accompany every Paper.

Two series of illustrations are required for every Paper accepted for reading. One set of Wall Diagrams, sufficiently large and boldly coloured, so as to be clearly visible when suspended in the Theatre of the Institution; and a set of drawings on tracing paper, to as small a scale as is consistent with distinctness, ready to be engraved for insertion in the Proceedings. The Wall Diagrams will be returned.

Papers which have been read at the Meetings of other Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted to competition for the Premiums.

The communications must be forwarded to the house of the Institution, No. 25, Great George Street, Westminster, S.W., London, where any further information may be obtained.

Charles Manby, *Honorary Secretary.*
James Forrest, *Secretary.*

The Institution of Civil Engineers,
25, *Great George Street*, *Westminster*, *S.W.*, *London.*
October, 1875.

EXCERPT BYE-LAWS, SECTION XV., CLAUSE 3.

"Every Paper, Map, Plan, Drawing, or Model, presented to the Institution, shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same in any way and at any time they may think proper. But should the Council refuse or delay the publication of such Paper beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary of his intention. No person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

NOTICE.

It has frequently occurred that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would therefore emphatically repeat, that the Institution must not, as a body, be considered responsible for the facts and opinions advanced in the Papers or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and the inquiry; but that such notice, or award, must not be considered as any expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

ORIGINAL COMMUNICATIONS

RECEIVED BETWEEN DECEMBER 1st, 1874, AND NOVEMBER 30th, 1875.

AUTHORS.

Airy, W. No. 1,457.—On the Probable Errors of Levelling; with Rules for the treatment of Accumulated Error.

Anderson, W. No. 1,442.—Notes of a Visit made to some Peat Works near St. Petersburg, in May 1875.

Barton, J. No. 1,435.—Carlingford Lough and Greenore.

Beaumont, W. W. No. 1,453.—The Fracture of Railway Tires.

Bontemps, C. No. 1,445.—On the Movement of Fluids under Normal Conditions.

Brunton, R. H. No. 1,451.—The Japan Lights.

Clark, D. K. No. 1,450.—The St. Gothard Tunnel.

Cross-Buchanan, W. No. 1,380.—Description of the Mexican Railway.

Culley, R. S., and Sabine, R. No. 1,439.—The Pneumatic Transmission of Telegrams.

Deacon, G. F. No. 1,431.—On the systems of Constant and Intermittent Water Supply, and the Prevention of Waste, with special reference to the Restoration of Constant Service in Liverpool.

Dixon, J. No. 1,428.—On the Use of Wrought-iron and Concrete Columns in the Construction of Viaduct Piers.

Donaldson, W. No. 1,432.—Rainfall in the Lake District of England.

Findlay, G. No. 1,419.—The Working of Railways.

Fuller, G. No. 1,426.—Curve of Equilibrium for a Rigid Arch.

Gamble, J. G. No. 1,449.—Brighton Intercepting and Outfall Sewers.

Gaudard, J. No. 1,455.—On the Conditions of Resistance of Swing Bridges.

Gordon, R. No. 1,425.—On the Flow of Water in Open Channels.

Grover, J. W. No. 1,422.—Railways of the Future, as affected by Rolling Stock Reforms.

Hackney, W. No. 1,434.—The Manufacture of Steel.

Harrison, J. T. No. 1,421.—Railway Statistics, 1873-4.

AUTHORS.

Hartley, Sir C. No. 1,413.—Notes on Public Works in the United States.

Hawkshaw, J. C. No. 1,417.—The Construction of the Albert Dock at Kingston-upon-Hull.

Hayter, H. No. 1,454.—Holyhead New Harbour.

Holmes-à-Court, Hon A. W. No. 1,414.—The Waterworks of Basse Terre, St. Kitts.

Kinahan, G. H. No. 1,436.—The Lagoons on the S.E. Coast of Ireland.

————. No. 1,437.—The Origin of Dover Strait.

Lancaster, C. W. No. 1,411.—On the Erosion of the Bore in Heavy Guns, and the Means for its Prevention; with further suggestions for the Improvement of Muzzle-loading Projectiles.

Luke, W. No. 1,446.—A concise Account of the new Workshops and other buildings constructed for the Punjáb and Delhi Railways at Lahore.

McAlpine, W. J. No. 1,441.—The Slopes of Subterranean Watercourses.

Morrison, G. J. No. 1,443.—The Ventilation and Working of Railway Tunnels.

Peacock, T. No. 1,440.—Stamp-perforating Machines. Continuous Variable Feed Motion.

Price, W. H. No. 1,447.—Manora Breakwater, Kurrachee.

Remington, G. No. 1,438.—Tunnelling the Channel.

Ross, O. C. D. No. 1,424.—Petroleum and other Mineral Oils applied to the Manufacture of Gas.

Sandberg, C. P. No. 1,412.—Engineering in Sweden.

Shoolbred, J. N. No. 1,427.—On the Changes in the Tidal Portion of the River Mersey and its Estuary.

Smith, J. T. No. 1,429.—Bessemer Steel Rails.

Smythies, J. K. No. 1,459.—On the Power required for Flight.

Stevenson, D. A. No. 1,456.—Dhu Heartach Lighthouse.

Sugg, W. No. 1,420.—On a new Method of Estimating the Illuminating Power of Coal Gas.

Tatam, E. J. No. 1,418.—History of the River Welland.

Watson, T. C. No. 1,415.—Description of the Use of Fascines in the Public Works of Holland.

Wheeler, W. H. No. 1,458.—A Description of the Fascine Work used for Training the Outfall of the Fen Rivers; with the effect of the training on the warping of the Foreshores, and of the value of the same for Inclosure and Reclamation.

Wright, Sir W. No. 1,416.—The Hull Docks.

LIST OF DONORS TO THE LIBRARY.

FROM DECEMBER 1, 1874, TO NOVEMBER 30, 1875.

THE GOVERNMENTS OF

Austro-Hungary.
Bavaria.
Belgium.
Denmark.
France.
Italy.
Russia.
The United States of America.

THE COLONIAL GOVERNMENTS OF

Canada.
Cape of Good Hope.
New South Wales.
New Zealand.
Queensland.
South Australia.
Tasmania.
Victoria.

PUBLIC DEPARTMENTS.

Admiralty.
Colonial Office.
Great Seal Patent Office.
India Office.
Local Government Board.
Meteorological Office.
Standard Weight and Measure Department (Board of Trade).

ACADEMIES, ASSOCIATIONS, COLLEGES, COMMITTEES, INSTITUTES, INSTITUTIONS, OBSERVATORIES, SOCIETIES, SCHOOLS, UNIONS AND UNIVERSITIES.

Academies.

American Academy of Arts and Sciences.
Royal Irish Academy.

Associations.

Association of Civil Engineers of Portugal.
Association of Past Pupils of the Engineering School of Liége.
Board of Railroad Commissioners of Massachusetts.
British Association for the Advancement of Science.
British Association of Gas Managers.
Canal Association.
East India Association.
London Association of Foremen Engineers.
Manchester Steam Users' Association.
Railway Association of America.
Swedish Association of Engineers.

Colleges.

College of Engineers and Architects of Milan.
King's College, Nova Scotia.
Thomason Civil Engineering College.
University College, London.

Committee.

Forge Committee of France.

Institutes.

American Institute of Mining Engineers.
Canadian Institute.
Chesterfield and Derbyshire Institute of Engineers.
Franklin Institute, Philadelphia.
Iron and Steel Institute.
North of England Institute of Mining and Mechanical Engineers.
Peabody Institute.
Royal Institute of British Architects.
Royal Institute of Engineers of Holland.
Royal Institute of Lombardy.
Sassoon Mechanics' Institute.
Stevens Institute of Technology.

Institutions.

Cleveland Institution of Engineers.
Institution of Architects and Engineers of Hanover.
Institution of Civil Engineers of Ireland.
Institution of Engineers and Shipbuilders in Scotland.
Institution of Mechanical Engineers.
Institution of Naval Architects.
Institution of Surveyors.
London Institution.
Royal Artillery Institution.
Royal Institution of Great Britain.
Royal National Life-Boat Institution.
Royal United Service Institution.
Smithsonian Institution.
South Wales Institute of Engineers.

Observatories.

Kew Observatory.
Royal Observatory, Edinburgh.

Royal Observatory, Greenwich.
Toronto Observatory.

Schools.

Royal Polytechnic School of Hanover.
School of Bridges and Roads of France.
School of Military Engineering, Chatham.

Societies.

Aeronautical Society.
American Society of Civil Engineers.
Asiatic Society of Bengal.
Chemical Society.
Edinburgh and Leith Engineers Society.
Geological Society.
Hungarian Society of Engineers.
Liverpool Literary and Philosophical Society.
Manchester Literary and Philosophical Society.
Meteorological Society.
Physical Society of London.
Royal Agricultural Society.
Royal Astronomical Society.
Royal Dublin Society.
Royal Geographical Society.
Royal Geological Society of Ireland.
Royal Scottish Society of Arts.
Royal Society of Edinburgh.
Royal Society of London.
Royal Society of Victoria.
Scientific and Mechanical Society of Manchester.
Scientific Industrial Society of Marseilles.
Society of Arts.
Society of Biblical Archæology.
Society of Civil Engineers of France.
Society of Engineers.
Society of Engineers and Architects of Saxony.
Society of Engineers and Architects of Turin.
Society of Engineers of Hungary.
Society of Mining Engineers, Madrid.
Society of Telegraph Engineers.
Statistical Society.

Union.

Art Union of London.

Universities.

University of Glasgow.
University of Michigan.

PROPRIETORS OF THE FOLLOWING PAPERS AND PERIODICALS.

Annales Industrielles.
Architect.
Athenæum.
British Architect.
British Commercial Gazette.
Builder.
Colliery Guardian.
Colonies.
Electrical News.
Emery Grinder.
Engineer.
Engineering.
Engineering and Building Times.
Engineering and Mining Journal.
Gas Lighting.
Irish Builder.
Iron.
Iron and Coal Trade Circular.
Iron Trade Circular.
Journal of Applied Science.
L'Ingegneria Civile e le Arti Industriali.
Mining World.
National Car Builder.
Photographic Journal.
Practical Magazine.
Revue Générale de l'Architecture et des Travaux Publics.
Sanitary Review.
Telegraphic Journal.
The Road.
The Western.

MISCELLANEOUS.

Meteorological Office of Canada.
Patent Law Committee.
Railway Commissioners.
Royal Commissioners of the Vienna Universal Exhibition.
Sydney Sewage & Health Board.
U.S. Railroad Commissioners.

PRIVATE INDIVIDUALS.

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Abernethy, J.
Adamson, D.
Addy, J.
Agent-General for New Zealand.
Aitken, R.
Akerman, R.

B.

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Baker, B.
Balfour, D.

G.

Gabrielli, A.
Gerwig, R.
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Gordon, J.
Gordon, R.
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Greaves, C.
Greene, C. E.
Greene, D. M.
Gregory, C. H.
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Gruner, L.
Guthrie, E.

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Hagen, Dr. G.
Handyside, H.
Hartley, Sir C.
Hawkshaw, Sir J.
Haywood, W.
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Hildebrandt, A.
Hildred, J.
Hirn, G. A.
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Hunt, R.

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Isaacs, L. H.

J.

Jackson, L.
James, S. H.
Janoyer, J.

K.

Keefer, S.
Kenwood, J.
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SECT. II.—OTHER SELECTED PAPERS.

No. 1,463.—"Investigation of the Motion of Light Carriers in Pneumatic Tubes, when the Air is in continuous or permanent motion."[1] By Professor WILLIAM CAWTHORNE UNWIN, B.Sc., Assoc. Inst. C.E.

IN the following theory it is assumed that by far the larger part of the work done in working long pneumatic tubes is expended in overcoming frictional resistances within the tube, and that only a small part remains as energy of motion in the air leaving the tube. The work expended in friction generates heat which for the most part must be developed in and given back to the air. If the earth surrounding the tube is very much hotter or colder than the tube, some heat would be transmitted through the tube and the temperature of the air would change; but, in the experiments thus far made, this does not seem to have been the case, and if no heat is transmitted, the air in the tube must remain sensibly at the same temperature during its expansion; or, in other words, the expansion will be isothermal expansion, the heat generated by friction exactly neutralising the cooling due to the work done. The experiments of Messrs. Culley and Sabine show that the change of temperature in the tube is very slight, compared with what it would be in adiabatic expansion.

The equation of condition which expresses the law of expansion when the temperature remains constant is

$$p\,v = \text{constant},$$

p being the intensity of pressure, and v the specific volume of the air (volume of 1 lb.) at any moment during the expansion. It would appear that this law is equally true for dry and moist air, so long as the temperature is maintained. If, however, there is any fall of temperature in the tube due to transmission of heat through its sides, the vapour in the air will partially condense, and the law of expansion will be $p\,v^n =$ constant where n is greater than unity. Looking to the fact that steam gives up

[1] This investigation has reference to the experiments and calculations in the Paper by Messrs. Culley and Sabine, read before the Institution in November 1875, and was communicated during the discussion on Pneumatic Transmission.

heat much more easily to a metal tube than dry air, it would seem desirable, either to work the tubes at a temperature not greater than the temperature of the soil, or to use air as dry as possible. It is quite possible, when very moist air is used, initially of a higher temperature than the tubes, that the air takes ultimately, during its flow, the temperature of the tubes; and that if initially it is saturated with vapour of the initial temperature, it leaves the tube saturated with vapour of the terminal temperature, the difference between these two quantities having been condensed and left in the tube. It is obvious that this would lead to difficulty in working, and that either dry air should be used, or it should be used at a temperature which does not lead to condensation.

Differential Equation of the Motion of a Light Carrier in a long level Pneumatic Tube.

For the relation between the pressure and volume of the air, assumed to remain at nearly constant temperature,

$$p\,v = c\,\mathrm{T} = \text{constant} \quad . \quad . \quad . \quad (1)$$

where p = intensity of (absolute) pressure in lbs. per square foot; v = volume of 1 lb. of air in cubic feet; T = absolute temperature Fahr., and c, a constant whose value is about 53·15. Taking the value of T at 521°, corresponding to 60° on the ordinary scale,

$$p\,v = 27{,}690 \text{ ft. lbs.} \quad . \quad . \quad . \quad (2)$$

The equation of continuity which expresses that the same weight of air passes each section in the unit of time, which is necessarily true if the permanent regime of the tube is established, is

$$\frac{\Omega\,u}{v} = \mathrm{W} = \text{constant} \quad . \quad . \quad . \quad (3)$$

where Ω is the area of a section of the tube, u the velocity, and v the specific volume of the air at that section; W the weight of air passing the section per second. The equation becomes, if combined with (2),

$$\Omega\,u\,p = c\,\mathrm{T}\,\mathrm{W} = 27{,}690 \text{ W.} \quad . \quad . \quad . \quad (3a)$$

The head lost in friction per unit length of pipe and per lb. of air is

$$\frac{\zeta}{d}\,\frac{u^2}{2g},$$

where ζ is the co-efficient of friction, and d the diameter of the tube. Putting $H = \frac{u^2}{2g}$, and taking the friction for an element of the tube of length $d\,l$, the head lost in friction is

$$\zeta \frac{H}{d} D l \quad . \quad . \quad . \quad (4)$$

The equation of work for 1 lb. of air flowing in the tube is

$$D H + v D p - \zeta \frac{H}{d} D l = 0 \quad . \quad . \quad . \quad (5)$$

The first term expresses the change of energy of motion; the second, the work due to expansion; the third, the work lost in friction. From (5) and (1)

$$\frac{D H}{H} + \frac{c T}{p} \frac{D p}{H} - \zeta \frac{D l}{d} = 0;$$

and by the aid of (3) it follows that

$$\frac{d H}{H} + \frac{2 g \Omega^2 p}{W^2 c T} \cdot dp - \zeta \frac{d l}{d} = 0 \quad . \quad . \quad . \quad (5a)$$

For tubes of uniform diameter Ω and d are constant; for permanent motion W is constant; and for isothermal expansion T is constant. Integrating

$$\log. H + \frac{g \Omega^2 p^2}{W^2 c T} - \zeta \frac{l}{d} = \text{constant.}$$

For $\quad l = 0$ let $H = H_0$ and $p = p_0$
$\quad l = L$ let $H = H_1$ and $p = p_1$

$$\log. \frac{H_1}{H_0} + \frac{g \Omega^2}{W^2 c T} (p_1^2 - p_0^2) = \zeta \frac{L}{d} \quad . \quad . \quad (6)$$

which is the general equation of the motion of the air in the assumed conditions. It must be understood that p_0 is always the less and p_1 the greater pressure, and that L is measured from that end of the tube at which the pressure is less.

By replacing W and H,

$$\log. \frac{p_0}{p_1} + \frac{g c T}{p_1^2 u_1^2} (p_1^2 - p_0^2) = \zeta \frac{L}{d} \quad . \quad . \quad . \quad (7)$$

which gives for the initial velocity

$$u_1 = \sqrt{\left\{ \frac{g c T (p_1^2 - p_0^2)}{p_1^2 \left(\zeta \frac{L}{d} - \log. \frac{p_0}{p_1} \right)} \right\}} \quad . \quad . \quad . \quad (8)$$

When L is great, log. $\frac{p_0}{p_1}$ is comparatively small, and then

$$u_1 = \sqrt{\left\{\frac{g\,c\,\mathrm{T}\,d}{\zeta \mathrm{L}} \frac{p_1^2 - p_0^2}{p_1^2}\right\}} \quad . \quad . \quad . \quad . \quad . \quad (8a)$$

or, approximately,

$$u_1 = \left(1 \cdot 1319 - 0 \cdot 7264\,\frac{p_0}{p_1}\right)\sqrt{\left\{\frac{g\,c\,\mathrm{T}\,d}{\zeta \mathrm{L}}\right\}} \quad . \quad . \quad . \quad (8b)$$

Law of Distribution of Pressure in the Tube.

(Figs. 30 and 31, pp. 153 and 154.)

From the equation (7) it results that for the pressure p, at a point l feet from the end where the pressure is least

$$p = \sqrt{\left\{\zeta \frac{l}{d}\;\frac{p_0\,u_0^2}{g\,c\,\mathrm{T}} + p_0^2\right\}} \quad . \quad . \quad . \quad . \quad (9)$$

which is of the form $p = \sqrt{a\,l + b}$ for any given tube working with given end pressures. The curve of pressures is therefore a parabola with horizontal axis, that is, if it be assumed as approximately true that the frictional resistance is proportional to the square of the velocity. In Messrs. Culley and Sabine's Paper two experiments are given on the pressure at the centre of a long tube. These experiments form a test of the above expression.

Exper. I.—Pressure-working: $p_0 = 15$ lbs.; $p_1 = 24$ lbs.; L = 8,454 feet.

From these data $a = 0 \cdot 0415$.

Hence $$p = \sqrt{\cdot 0415\,l + 15^2}.$$

This gives for the middle of the tube $p = 20 \cdot 02$ lbs. The observed pressure was $19 \cdot 87$ lbs.; difference $= +\,0 \cdot 15$ lb.

Exper. II.—$p_0 = 7 \cdot 875$; $p_1 = 15 \cdot 0$; L as before. From these it follows that $a = 0 \cdot 0193$.

Hence $$p = \sqrt{\cdot 0193\,l + 7 \cdot 875^2}.$$

This gives for the centre of the tube $11 \cdot 98$. The observed pressure was $12 \cdot 125$; difference $= -\,0 \cdot 127$ lb.

The error, from assuming the pressure at the centre to be a mean of the end pressures, is much greater. Fig. 31 (p. 154) shows the curves of pressure for these two experiments. Possibly some difference of level in the tubes may explain the divergence of the calculated from the observed middle pressure.

Time of Transit through the Tube.

Putting t for the time of transit from 0 to L in seconds,

$$t = \int_0^L \frac{Dl}{u};$$

from (5a), neglecting $\frac{DH}{H}$,

$$Dl = \frac{2\,d\,g\,\Omega^2 p}{\zeta\,W^2 c\,T}\,Dp;$$

from (3) and (1),

$$u = \frac{W\,c\,T}{p\,\Omega};$$

$$\frac{Dl}{u} = \frac{2\,g\,d\,\Omega^3 p^2}{\zeta\,W^3 c^2 T^2}\,Dp;$$

$$t = \int_{p_0}^{p_1} \frac{2\,g\,d\,\Omega^3}{\zeta\,W^3 c^2 T^2}\,p^2\,Dp;$$

$$= \frac{2\,g\,d\,\Omega^3}{3\zeta\,W^3 c^2 T^2}\,(p_1^3 - p_0^3).$$

But

$$W = \frac{p_1 u_1 \Omega}{c\,T};$$

$$t = \frac{2}{3}\,\frac{g\,d\,c\,T}{\zeta\,p_1^3 u_1^3}\,(p_1^3 - p_0^3);$$

$$= \tfrac{2}{3}\,\frac{\zeta^{\frac{1}{2}} L^{\frac{3}{2}}}{(g\,c\,T\,d)^{\frac{1}{2}}}\,\frac{p_1^3 - p_0^3}{(p_1^2 - p_0^2)^{\frac{3}{2}}} \quad . \quad . \quad . \quad (10)$$

If there be inserted the value of T assumed in (2),

$$t = \cdot 000706\,\frac{\zeta^{\frac{1}{2}} L^{\frac{3}{2}}}{d^{\frac{1}{2}}}\,\frac{p_1^3 - p_0^3}{(p_1^2 - p_0^2)^{\frac{3}{2}}} \quad . \quad . \quad . \quad (10a)$$

which gives the time of transmission in terms of the initial and terminal pressures and the dimensions of the tube. The pressures may be taken in lbs. per square inch or per square foot in this formula.

Mean Velocity in the Tube.

The mean velocity is $L \div t$; or, for the value of T assumed in (10a),

$$u_{\text{mean}} = 1{,}416\,\sqrt{\frac{d}{\zeta L}}\,\frac{(p_1^2 - p_0^2)^{\frac{3}{2}}}{p_1^3 - p_0^3} \quad . \quad . \quad . \quad (11)$$

The following table gives some results calculated by the formula:

VACUUM-WORKING.						
Lbs. per Square Inch.		Velocities in Feet per Second for Lengths of Tube in Feet.				
p_0	p_1	1,000	2,000	3,000	4,000	5,000
5	15	99·4	70·3	57·4	49·7	44·5
10	15	67·2	47·5	38·8	34·4	30·1
PRESSURE-WORKING.						
15	20	57·2	40·5	33·0	28·6	25·6
15	25	74·6	52·7	43·1	37·3	33·3
15	30	84·7	60·0	49·0	42·4	37·9

It will be seen from this table that, for equal differences of pressure, the mean velocity is greater the lower the pressures are. The velocities are less with a pressure of 15 lbs. than with a vacuum of 5 lbs. It is easier, therefore, to obtain a high velocity with vacuum-working than with pressure-working.

LIMITING VELOCITY IN THE TUBE WHEN THE PRESSURE IS REDUCED AT ONE END INDEFINITELY.

If in the last equation there be put $p_0 = 0$, then

$$u'_{\text{mean}} = 1{,}416 \sqrt{\frac{d}{\zeta L}},$$

where the velocity is independent of the pressure at the receiving end, a result which apparently must be absurd. A similar result follows from Messrs. Culley and Sabine's formulæ. It is known that an absurd result follows when $p_0 = 0$ is inserted in Weisbach's formulæ for the flow of gases from orifices. There is probably a limit to the ratio of the initial and terminal pressures at which the formulæ cease to be true.

It would be extremely interesting to have some experiments with greater differences of pressure than those recorded in the Paper. For a tube like that between Central Station and Thames Street, 8,454 feet long, the limiting velocity by the formulæ above is about 40 feet per second. For shorter tubes it would be greater.

VELOCITY AT DIFFERENT POINTS IN THE TUBE.

Having obtained the initial velocity u_1 and the pressures at different points for a given tube, it is easy to find the velocity at any point of a tube through which the air is flowing.

From the equation of continuity for constant temperature,

$$u\,p = u_1\,p_1,$$

where u and p are the velocity at any point of the tube, and u_1 and p_1 the initial velocity and pressure. Then

$$u = \frac{u_1\,p_1}{p} \quad . \quad . \quad . \quad . \quad (12)$$

For the two experiments for which the pressures have already been calculated Fig. 30 gives also the curves of velocity. For the pressure experiment it results from (8a) $u_1 = 20\cdot5$ feet per second when $p_1 = 24$ lbs.; for the vacuum experiment $u_1 = 22\cdot3$ when $p_1 = 15$ lbs. The velocities at other points are given in the following table:—

Distance from Starting Point in Feet.	Velocity of Carrier.	
	Pressure Experiment.	Vacuum Experiment.
0	20·5	22·3
2,127	22·2	24·6
4,254	24·6	28·6
6,381	27·7	33·0
8,454	32·7	42·6

It will be seen that the velocity increases greatly towards that end of the tube where the pressure is least, which agrees with the statements in Mr. Carl Siemens' Paper. The difference of velocity is so great that it is evidently inaccurate to use a mean value of the velocity in determining the work expended in friction.

Comparison of the Transit Time with the Results of Messrs. Culley and Sabine's Experiments.

Two important data in the comparison are unfortunately omitted in the Paper. In all the experiments, the pressure at one end of the tube is the atmospheric pressure at the time, which is not recorded. It is necessary therefore to assume the value 14·7 lbs. per square inch in reducing the results. It is hardly possible, however, that in so extensive a series of experiments the atmospheric pressure was always the same, and it may have been ½ lb. greater or less than the assumed value. Then, also, no sufficient data are given of the temperature of the air in the tube. It is clear to the Author that the average temperature was higher in the pressure experiments than in the vacuum experiments, and the few data given in the Paper confirm this view. If the compressing pumps were worked with dry air and without a water injection, the temperature due to the compression might be taken, at least provisionally, as the temperature of the tubes; but the actual temperature of the

air entering the tubes was probably much less than this, partly from the presence of water in the pumps, and partly from cooling in the air reservoir. Looking at the few data given in the Paper, it seems fair to take the temperature in the vacuum experiments at 60° Fahr. The temperature in the pressure experiments is much less certain; probably it may have been at least 80°, and this value is assumed in the following reductions. If it had been taken higher, a somewhat closer agreement of the formula with the pressure experiments would have resulted.

The following table gives a comparison of the experiments in Table D, by Mr. Sabine (p. 79), with formula (10*a*), the experiments on intermittent transmission being omitted. The value of the coefficient ζ for each experiment is first calculated. The mean value of ζ is then found, and from that mean value the transit time is recalculated. The comparison of the calculated and observed transit times is a test of the applicability of the formula. The formulæ become

For 60° or T = 521° $$t = \cdot 000706 \frac{\zeta^{\frac{1}{2}} L^{\frac{3}{2}}}{d^{\frac{1}{2}}} \frac{p_1^3 - p_0^3}{(p_1^2 - p_0^2)^{\frac{3}{2}}}.$$

For 80° or T = 541° $$t = \cdot 000693 \frac{\zeta^{\frac{1}{2}} L^{\frac{3}{2}}}{d^{\frac{1}{2}}} \frac{p_1^3 - p_0^3}{(p_1^2 - p_0^2)^{\frac{3}{2}}}.$$

The mean value assumed for ζ is 0·028.

Number of Experiment.	Length of Tube.	Terminal Pressure.	Initial Pressure.	Transit Time in Seconds.	Co-efficient ζ	Calculated Transit Time.	Error of Formula in Seconds.
	Feet.	lbs.	lbs.			Seconds.	
			VACUUM EXPERIMENTS.				
	5,523	14·7	6·7	145	·02769	145·8	+0·8
	4,923	14·7	8·2	140	·02872	138·2	−1·8
	4,227	14·7	8·45	108	·02581	112·5	+4·5
	4,014	14·7	9·45	118	·02948	115·0	−3·0
	2,895	14·7	9·2	67	·02671	68·6	+1·6
	2,862	14·7	9·2	70	·03018	67·5	−2·5
	2,751	14·7	9·40	68	·03041	65·3	−2·7
	2,424	14·7	9·2	54	·02959	52·5	−1·5
	2,331	14·7	10·2	54	·02647	55·5	+1·5
			PRESSURE EXPERIMENTS.				
	5,523	22·7	14·7	175	·02541	183·4	+8·4
	4,923	21·2	14·7	173	·02999	167·0	−6·0
	4,227	22·83	14·7	121	·02748	122·3	+1·3
	4,014	23·2	14·7	106	·02541	111·2	+5·2
	3,576	20·2	14·7	99	·02239	110·8	+11·8

It will be observed that the calculated transit times agree extremely well with the observed transit times in the vacuum experiments. In the pressure experiments the errors are greater, possibly from the greater uncertainty of the data, especially as to temperature. The following points also may be noticed as possible causes of the discrepancies between the formula and the experiments:—

(1) The co-efficient of friction ζ is known not to be quite constant. It varies with the diameter of the tube and with the velocity of the air. It would not be difficult to assign a value for ζ which would make the formula fit the experiments more closely; but the data are not extensive enough to make the correction worth trying.

(2) The condensation of moisture in the tubes in the pressure experiments, in which the initial temperature was probably considerably higher than the temperature of the soil, may explain part of the errors of the pressure results. The Author, however, doubts that there was condensation to such an extent as to make an appreciable difference in the results.

Weight of the Air used per Second.

The weight of the air used per second (eq. 3*a*) is

$$W = \frac{\Omega u_1 p_1}{c\,T};$$

and from eq. (8*a*)

$$= \frac{\pi}{4}\sqrt{\left\{\frac{g\,d^5}{\zeta L c T}(p_1^2 - p_0^2)\right\}};$$

$$= \cdot 611\sqrt{\left\{\frac{d^5}{\zeta L T}(p_1^2 - p_0^2)\right\}} \quad . \quad . \quad . \quad (13)$$

in which W is in lbs., if p_1 and p_0 are in lbs. per square foot. A simpler approximate expression for W is

$$W = (\cdot 6916\,p_1 - \cdot 4438\,p_0)\left(\frac{d^5}{\zeta L T}\right)^{\frac{1}{2}}.$$

Work done in Compressing the Air and Forcing it into the Tube, or in Exhausting Air from the Tube.

When the tube is worked by pressure, air is taken from the atmosphere, compressed adiabatically to the working pressure p_1, and under that pressure forced into the tube. On the other hand, when the tube is worked by vacuum, air is taken from the tube at

some pressure p_0, less than atmospheric pressure, compressed adiabatically to atmospheric pressure, and under that pressure forced into the atmosphere. Both operations are the same in kind, and the work expended in compressing or exhausting is calculated in the same way. In tubes worked by pressure the heat generated by compression would, if the air were dry, tend to economy of working. But in vacuum tubes the heat generated by compression is at once wasted. The influence on the work done of the vapour generated in the pump, which has the effect of lowering the temperature and of increasing the volume of the compressed gas, will be neglected; the problem will be treated as if it related to dry air.

For simplicity let the pump be single acting, and let the quantity of air compressed in one stroke be 1 lb. Let p_0 v_0 T_0 be its initial, and p_1 v_1 T_1 its final pressure, specific volume, and absolute temperature. For pressure-working p_0 is atmospheric pressure; for vacuum-working p_1 is atmospheric pressure.

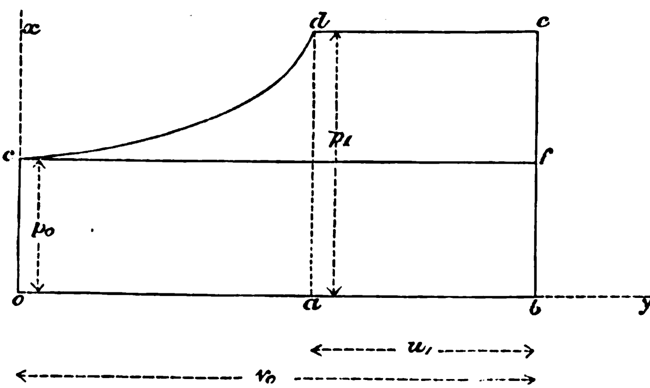

Fig. I.—Indicator Diagram of Pump.

Fig. I. represents the indicator diagram for one double stroke of the pump. Suppose the piston at the end of its stroke and the pump empty. As the piston moves from *b* towards *o*, it draws in at the pressure p_0 a volume v_0 of air. Throughout this stroke the pressure (neglecting frictional resistances) remains constant, and the work done by the pressure of the air on the piston is the area of the rectangle *o c f b*. As the piston returns it compresses the air, the pressure at each point being represented by the adiabatic compression curve *c d*, and the whole work done by the piston on the air, during this part of the stroke, is the area *o c d a*. When

the volume v_0 is reduced to v_1 the delivery valves open, and the air is forced, at constant pressure, into the tube or the atmosphere, and the work done by the piston on the air in this part of the stroke is the area *a d e b*. The effective work per stroke is therefore *ocdeb* − *ocfb*, or is the area *fcde*.

Work done in Exhausting or Compressing per Pound of Air.

For adiabatic compression—

$$p v^\gamma = p_1 v_1^\gamma = p_0 v_0^\gamma = \text{constant} = m,$$

where γ for dry air has the value 1·41.

The area *oeda* representing the work done during compression

$$= -\int_{v_0}^{v_1} p\,dv - m\int_{v_0}^{v_1} v^{-\gamma}\,dv;$$

$$= \frac{m}{\gamma-1}\left\{\frac{1}{v_1^{\gamma-1}} - \frac{1}{v_0^{\gamma-1}}\right\};$$

$$= \frac{p_0 v_0}{\gamma-1}\left\{\left(\frac{v_0}{v_1}\right)^{\gamma-1} - 1\right\} \text{ or } = \frac{p_1 v_1}{\gamma-1}\left\{1 - \left(\frac{v_1}{v_0}\right)^{\gamma-1}\right\}$$

The area *adeb* − *ocfb*

$$= p_1 v_1 - p_0 v_0;$$

$$= p_0 v_0\left\{\left(\frac{v_0}{v_1}\right)^{\gamma-1} - 1\right\} \text{ or } = p_1 v_1\left\{1 - \left(\frac{v_1}{v_0}\right)^{\gamma-1}\right\}$$

Hence effective work per stroke in compressing 1 lb. of air

$$= \frac{p_0 v_0}{\gamma-1}\left\{\left(\frac{v_0}{v_1}\right)^{\gamma-1} - 1\right\} + p_0 v_0\left\{\left(\frac{v_0}{v_1}\right)^{\gamma-1} - 1\right\}$$

$$= p_0 v_0 \frac{\gamma}{\gamma-1}\left\{\left(\frac{v_0}{v_1}\right)^{\gamma-1} - 1\right\};$$

or

$$= p_1 v_1 \frac{\gamma}{\gamma-1}\left\{1 - \left(\frac{v_1}{v_0}\right)^{\gamma-1}\right\} \quad . \quad . \quad . \quad . \quad . \quad (14)$$

From equation (13), $\left(\frac{p_1}{p_0}\right)^{\frac{1}{\gamma}} = \frac{v_0}{v_1}.$

Hence effective work per lb. of compressed air

$$= \text{U} = p_0 v_0 \frac{\gamma}{\gamma-1}\left\{\left(\frac{p_1}{p_0}\right)^{\frac{\gamma-1}{\gamma}} - 1\right\} = p_1 v_1 \frac{\gamma}{\gamma-1}\left\{1 - \left(\frac{p_0}{p_1}\right)^{\frac{\gamma-1}{\gamma}}\right\} \quad . \quad (15)$$

Inserting $\gamma = 1 \cdot 41$ then

$$U = 3 \cdot 45\, p_0 v_0 \left\{ \left(\frac{p_1}{p_0} \right)^{\cdot 29} - 1 \right\} = 3 \cdot 45\, p_1 v_1 \left\{ 1 - \left(\frac{p_0}{p_1} \right)^{\cdot 29} \right\} . \quad (15a)$$

Rise of Temperature during Compression.

In adiabatic compression—

$$c\, T_1\, v_1^{\gamma - 1} = c\, T_0\, v_0^{\gamma - 1}$$

$$\frac{T_1}{T_0} = \left(\frac{v_0}{v_1} \right)^{\gamma - 1} = \left(\frac{p_1}{p_0} \right)^{\frac{\gamma - 1}{\gamma}} .$$

Using this value the equation above becomes more simple :—

$$U = 3 \cdot 45\, p_0 v_0 \left(\frac{T_1}{T_0} - 1 \right) = 3 \cdot 45\, p_1 v_1 \left(1 - \frac{T_0}{T_1} \right) \quad . \quad . \quad (16)$$

Total Work Expended in Maintaining the Flow of Air in the Tubes.

Combining equations (13) and (15*a*), we get for the expenditure of work per second—

For pressure tubes, (p_0 = atmospheric pressure)

$$2 \cdot 108\, p_0 v_0 \left\{ \left(\frac{p_1}{p_0} \right)^{\cdot 29} - 1 \right\} \left\{ \frac{d^5}{\zeta L T} (p_1^2 - p_0^2) \right\}^{\frac{1}{2}} \text{ ft. lbs. per sec. } (17)$$

For vacuum tubes, (p_1 = atmospheric pressure)

$$2 \cdot 108\, p_1 v_1 \left\{ 1 - \left(\frac{p_0}{p_1} \right)^{\cdot 29} \right\} \left\{ \frac{d^5}{\zeta L T} (p_1^2 - p_0^2) \right\}^{\frac{1}{2}} \text{ ft. lbs. per sec. } (18)$$

Or, in horse-power :—

Pressure-working—

$$HP. = \cdot 00383\, p_0 v_0 \left(\frac{d^5}{\zeta L T} \right)^{\frac{1}{2}} (p_1^2 - p_0^2)^{\frac{1}{2}} \left\{ \left(\frac{p_1}{p_0} \right)^{\cdot 29} - 1 \right\} . \quad (17a)$$

Vacuum-working—

$$HP. = \cdot 00383\, p_1 v_1 \left(\frac{d^5}{\zeta L T} \right)^{\frac{1}{2}} (p_1^2 - p_0^2)^{\frac{1}{2}} \left\{ 1 - \left(\frac{p_0}{p_1} \right)^{\cdot 29} \right\} . \quad (18a)$$

In which formulæ the pressures are in lbs. per square foot.

The HP. given by these formulæ requires to be multiplied by a number expressing the counter efficiency of the pumping machinery to obtain the gross power required.

Relative Economy of Pressure and Vacuum Working.

Let the following case be assumed. Tube 5,000 feet long; $\cdot 0 \cdot 1823$ foot diameter; $T = 521°$; $p_0\, v_0$ for pressure-working; and $p_1\, v_1$ for vacuum-working = 27,690 foot lbs. (equation 2); $\zeta = \cdot 028$.

Then for equal differences of pressure the following values are found for the mean velocity in the tube, and for the HP. expended in working it:—

	Pressures. p_0	Pressures. p_1	Mean Velocity. Feet per Second.	HP.
Vacuum	10	15	30·1	0·9945
Pressure	15	20	25·6	0·9137
Vacuum	5	15	44·5	3·097
Pressure	15	30	37·9	4·652

It is clear that, for equal velocities, pressure-working requires more power than vacuum-working. Further, it will be seen that, for an increase of velocity of about one-half, the power expended is increased about four times.

If at the Post Office no economy of power has been observed in working the vacuum tubes as compared with the pressure tubes, that may very probably be due to two causes: (1) the vacuum in the Post Office tubes is not so low as to make the economy of power considerable; (2) the velocity of the carriers in the vacuum tubes may be rather greater than in the pressure tubes. This slight increase of velocity may easily absorb the power which would otherwise be economised, and the benefit of vacuum-working would thus be masked. It is curious that in the first five tubes mentioned in the Paper on "Pneumatic Transmission" by Mr. Sabine, Table D, the velocity for continuous pressure is less than for continuous vacuum. The sixth tube is an exception. For the other tubes, experiments both with pressure and vacuum are not given.

No. 1,379.—"The Applications of Asphalt." By ERNEST CHABRIER, Civil Engineer, Paris. (Translated by W. H. DELANO, Assoc. Inst. C.E.)

EARLY STUDIES.

THE nature of asphalt was first seriously discussed in a report by M. Leon Malo, C.E., published in the Annales des Ponts et Chaussées in 1861.[1] This report, written after the author had resided for several years at the mines of Seyssel, in the capacity of manager and superintendent, passed through several editions, and latterly formed the basis of a volume, published in Paris, in 1866, which is the only complete work on the subject.

Following the precedent of M. Malo, the word "asphalt" will be used to designate bituminous limestone, although scientific men regard asphalt as being synonymous with the matter impregnating the limestone, viz., bitumen.

Asphalt is pure carbonate of lime naturally impregnated with bitumen in very variable proportions; but which for road-making should be limited to between 7 and 12 per cent. It is found in beds, frequently of great extent, for the most part of a lenticular shape, from 23 to 26 feet in thickness, and sometimes separated by other beds of entirely white limestone, the nature of which seems to be the same as that of the limestone impregnated with bitumen. It takes an irregular fracture, without definite cleavage. The texture and grain vary with the layers. The grain should be regular and homogeneous, not too close. Exposed to the atmosphere, asphalt gradually assumes a grey, almost a white tint, caused by the bitumen evaporating from the surface and leaving a film of limestone.

HISTORY.

In a pamphlet published in 1721, a Greek professor, Eirini d'Eyrinys, mentions the discovery he had made, ten years before, in the Val de Travers, canton Neufchatel, of a mine of asphalt similar to the beds of that substance existing in the valley of

[1] *Vide* 4e Série, 1er semestre, tome I, p. 69.

Siddim, near Babylon.[1] He enumerates at length the advantages of this substance; regarding it as a panacea for human ills, and at the same time as a substitute for mortar in buildings. He states that its employment as cement is antediluvian, and in support of his assertion cites the Book of Genesis, ch. vi., v. 14, where in relation to Noah's Ark it is stated, "and shalt pitch (asphalt) it, within and without with pitch (asphalt);" and, again, ch. xi., v. 3, "and slime (asphalt) had they for mortar." He does not hesitate to attribute the historical resistance of the Babylonian buildings to the employment, as mortar, of asphalt from the valley of Siddim; and asserts that the walls of the famous hanging gardens of Babylon were coated with asphaltic mastic, and that the Tower of Babel itself would not have held together without this substance.

The use of asphaltic mastic tends to justify these somewhat enthusiastic hypotheses, and it is difficult to explain why no trace of its employment should be found amongst the western nations. The details given by D'Eyrinys on the curative properties of "asphaltic balm," both for men and for animals, are very curious, but less interesting than the advantages claimed for the use, in buildings, of asphaltic mastic, which he calls natural cement. He cites, with a thorough conviction of its success, instances of works carried out with it, as cisterns, jointing of paving stones and flags, coating of terraces, &c. It would, however, appear that his successors in the working of the Val de Travers mine contented themselves with extracting asphalt for medicinal purposes, disregarding its merits as a material for paving, though this was afterwards destined to be its principal application.

Until the end of the century only the extraction of bitumen was thought of, as is proved by the concession made by the French Directory in the year V. of the Republic (1797), to a man named Secretan, of all the country situated between Seyssel and Bellegarde, a tract of about 14 miles in length by 1½ mile in width on both banks of the Rhone. Secretan had certainly no other object than to extract the bitumen from the bituminous earth and sandstone, from which it is more easily separated than from the limestone, as is proved by the state of the works at that time; consequently when, later, the employment of asphaltic mastic and the quarrying of the bituminous limestone began to increase, many disputes arose as to the terms of the concession. It was claimed that no right to quarry the limestone existed; the word "mine"

[1] "Dissertation sur l'Asphalte, ou Ciment Naturel." 8vo. Paris.

was even disputed, only open workings were allowed. A lawsuit was the result, and it was not until 1845 that the question was resolved by a decision of the Council of State, which maintained to the concessionary the title of mine, and the right to extract limestone and bitumen, notwithstanding the contrary opinion of the minister. In 1834 M. de Puvis, in the "Annales des Mines,"[1] furnished particulars of what was being done at Pyrimont for the manufacture of asphaltic mastic. Without entering into a subject so new, and without inviting his colleagues in other parts of France to the discovery of similar seams, the author simply gave expression to his doubts, and noticed the heavy expenses of starting works. He recorded, however, the confidence which was already felt in the results of the asphaltic mastic footpaths of the Morand Bridge at Lyons, though the price of bitumen was at that time 800 francs (£31 15*s.*) per ton, whereas the price is now 300 francs (£11 18*s.*) per ton, and the mastic which was then sold at 140 francs (£5 11*s.*) per ton is now sold at 70 francs (£2 15*s.* 6*d.*) per ton. However slowly the natural cement of Eirini d'Eyrinys came into general use, the results were such that engineers did not fail to notice them, and to aid in the development of such remarkable qualities; but speculators intervened, and led the public into acts of folly. As soon as the first footpaths were made, it was maintained that all towns would be paved with this new material.

The first, and perhaps the only inquiry by an engineer at that time into the subject of asphalt then appeared, but it referred to mastic instead of bituminous limestone. Analysis proved the composition to be limestone and bitumen, and this enabled an imitation to be produced. A panic then ensued, which led to the breaking up of the asphalt companies. The remnants of these various undertakings did not agree to amalgamate their interests until the formation, in 1855, of the General Asphalt Company, the management of which being confided to a civil engineer, led to the engagement of another civil engineer, M. Malo, as manager of the mines at Pyrimont. By prudence, in spite of low prices, which the successive opening of railways alone made bearable, operations were begun, and from that moment must be dated the regular development of the asphalt industry.

Mechanical apparatus superseded manual labour; the rock was quarried according to the most approved rules of mining, instead of being simply dug where it cropped up. The primitive method

[1] *Vide* 3e Série, tome 6, p. 179.

of mixing the mastic in small open cauldrons, and thus subjecting for weeks the inhabitants and the luxurious portions of the city to its noisome fumes, was abandoned, and means were found of transporting the mastic hot and ready mixed to the work, so that it could be applied at once. Besides these modifications, particular attention was paid to the process, then quite new, of applying compressed asphalt, which allowed of the employment of the bituminous limestone in its natural state without admixture.

A trial on a small scale had been made in Paris in 1854, under M. Vaudry, then roadway engineer; and another on a more important scale was made at the expense of the Company in the square in front of the Palais Royal in 1858. At this time the Rue St. Honoré had a traffic of thirteen thousand one-horse vehicles daily, upon a width of roadway of 8 mètres (26 feet). The result was satisfactory, and the municipality decided to reserve, for this mode of paving, the streets comprised between the Madeleine and the Halles Centrales along the Rue de Rivoli. Machinery was prepared in proportion to the needs of the experiment, but the scheme was nearly jeopardised by the necessity of completing all the subterranean works of drainage, &c., before the asphalt was laid down. Thus the asphalt was applied upon soil recently disturbed to the depth of 10 feet to 12 feet. This induced instability of the subsoil, involving the breaking up of the layer of asphalt, 2 inches thick, which could not resist the subsidence of the foundation. Profiting by the experience thus gained, engineers in London insisted upon a thick layer of concrete for a foundation, which served to consolidate the soil.

Geological History of Asphalt.

The geological phenomena which produced asphalt have been little studied by men of science. The first theory is that bituminous vapours, meeting seams of limestone under favourable conditions of pressure and temperature, have penetrated the stone and become condensed therein. The examination of the beds would seem to negative this theory. Seams of limestone separate seams of asphalt, which limestone, though of the same nature as that containing the asphalt, is unimpregnated with bitumen. The contact of the two seams is clearly defined, and there is no exudation. Besides, the seams are never more impregnated in the middle than on the outside; rather the contrary.

Another hypothesis is based upon the often-demonstrated existence of bituminous springs under lakes. It has been supposed

that periods of deposition may have occurred under such conditions, that the molecules of limestone in suspension in the water have become mixed with the elements of bitumen; and that fortuitous circumstances caused the bitumen to fail. There would then be precipitated a white sediment, which would become impregnated on the return of the bituminous emanations: but when the repulsion which bitumen bears to damp substances is considered (simply wetting the fingers permits of its being touched without its adhering to them), there is little ground for belief in the existence of sufficient affinity between bitumen and limestone to support this theory.

Lastly, a Swiss geologist attributes the formation of asphalt to the presence of banks of the oyster called "Caprotine," capable of existing in deep seas. These animals, crushed by some convulsion of nature, afforded the bitumen said to be produced by all animal matter under certain conditions, as well as, in their shells, the limestone by which it was absorbed.

Extraction.

Bitumen is widely distributed in nature, but bituminous limestone is rare; indeed it has not been much sought after. The seams best known, which up to the present have supplied the demand for asphalt, are those of Seyssel and Val de Travers, both worked in the same manner on the surface, or in galleries, according to the position of the seams compared with the surface soil. Asphalt is quarried like limestone, with the advantage that the mine-holes can be made with an awl, and the stuff itself used for tamping.

Pulverisation.

Asphalt blocks must be pulverised before being used, and for this operation several processes have been tried.

1. Decrepitation, or breaking-up, takes advantage of the peculiar quality asphalt possesses of fusing, by the softening of the bitumen which holds together the limestone molecules. In the early stages of this process the asphalt was placed on heated iron plates called 'decrepitators'; but the stuff was spoiled by overheating, and by the bitumen being evaporated, so that the plan was abandoned.

2. At Seyssel, where the rock is harder, the decrepitators were replaced by crushing mills, which at an ordinary temperature produced a powder sifting well, but at a high temperature caused the rock to become sticky, and the mill to clog.

3. At the Val de Travers mines it was not possible to use crushing mills, or edge-runners revolving in a circular trough, on account of the nature of the rock; for they soon became covered with a layer of compressed asphalt, which had to be removed with a hammer and chisel.

4. With the extended use of asphalt all existing means for supplying the necessary quantity proved insufficient. Recourse was then had to plain rollers, which laminated the asphalt in thin sheets. The application of a little heat caused these sheets to fall to powder.

5. But the greatest improvement was the employment of Carr's disintegrator, first used by the Compagnie Générale des Asphaltes about 1867.

Asphalt reduced to powder admits of two distinct modes of application, viz., as compressed asphalt, which is obtained by heating the powder up to from 212° to 250° Fahrenheit, and causing the molecules to cohere under strong pressure; and as liquid asphalt, or asphaltic mastic, for which a manufacturing process is necessary. Then by heating the powder with an addition of from 5 to 8 per cent. of free bitumen, the latter causes the asphalt to melt, and gives a peculiar mastic which must be remelted before being employed. Although the introduction of compressed asphalt is of later date than asphaltic mastic, it will be described first, because the process is simpler, and is effected without the admixture of other matters.

II.—Compressed Asphalt.

The application of rock-asphalt to the construction of roads resulted from observing a fact of daily occurrence in asphalt mines. The detritus detached from the lumps of asphaltic rock, when crushed by the wheels of the carts employed on the works, forms on frequented roads a crust of superposed layers of compressed asphalt; but this effect is long in production, and only takes place in summer. In order to investigate this property of asphalt of reintegrating itself into blocks by compression, a series of experiments was undertaken, which proved that a certain degree of heat was required to render agglomeration easy. To effect this the apparatus for reducing the rock to powder was first employed, viz., the decrepitator, of boiler-plate slightly bowed out, placed above a fire-grate. The powder was spread over the plate, and frequently stirred. By this plan a careless workman might easily spoil a large portion of the material by overheating. Besides, the

powder when shovelled out lost heat rapidly. To mitigate these evils an apparatus analogous to a coffee-roaster was designed, viz., a closed cylinder slowly turning over a fire. The grate was movable, so that it might be replaced by a cart when the heating was complete. This apparatus, worked by suitable gearing, was fed at the axis end, and discharged the material by a trap in the circumference. Among the various attempts at preparing the powder, one was made of using steam. Blocks of asphalt inclosed in a cylinder were brought to the desired degree of heat by being subjected to a jet of steam from a portable engine. As soon as condensation ceased, the jet was turned off, the cylinder was emptied, and the blocks broken up. The powder thus produced was however spread with difficulty and irregularly; the rammers at times encountered parts thoroughly pulverised, at others refractory lumps requiring a much greater effort to make them into a level surface. Hence resulted inequality in the work; moreover, it was feared that the rock being impregnated by watery vapour might prevent the cohesion of the molecules.

The manner of spreading the powder over the soil previous to compression has varied considerably since works in asphalt became of importance. At first, when the rock was brought on to the ground like macadam, and decrepitated or comminuted on the spot, the small quantities of heated powder thus obtained necessitated the employment of rulers, which were placed across the street about 3 feet 3 inches to 5 feet apart, and limited the spreading or laying out of each batch. The powder within these boundaries was dressed down by hand with a wooden gauge. When, latterly, the heated powder was deposited from closed boxes with double sides, the guides were placed longitudinally in the street, so that it could be brought close to the work and used at once. These sections, spaced longitudinally at distances of 3 feet apart, required corresponding joints, which, although constituting a crucial test of the work, always stood well. At length it was found that asphalt cooled very slowly, and could be therefore allowed to remain for a considerable time in an open cart without inconvenience, and hence the use of gauges was abandoned; the workmen got into the habit of spreading the stuff with a rake to the required thickness completely across the street, and only made a joint where the work ceased for the day. To insure an equal thickness and regularity of the material, workmen skilled in the use of the rake were required. A mechanical rake, or spreader, which, whilst laying out the powder, would leave it at the proper thickness, is still a desideratum.

Compression by the Rammer.

Compression is effected either by rammers or by a roller. The employment of rammers had been impeded in the first instance by a tendency of the powder to adhere to the metal of which they were constructed and to agglomerate on it; their surfaces were planed without success; at last the difficulty was obviated by heating the rammers, when adherence ceased.

Steam Rammer.

The difficulty of relying upon even ramming, on account of the variation in the muscular efforts of the workmen, induced a persistent research for compression by mechanical means. Tolerable results were obtained as long as the work was done in narrow transverse strips, the compression being effected by a steam hammer moving on rails; but this ingenious system could not be applied to large works unless rails or rulers were laid beforehand.

The use of a roller was suggested by its constant employment in the construction of asphalt roads; but, besides the difficulty of draught, the powder was driven before it. Adhesion was prevented by covering the powder with a cloth, over which the roller was worked. As this system was not available for large surfaces, it was necessary to reduce considerably the weight of the roller, also to suspend to the axles a basket of live coal to prevent adherence and the displacement of the powder. The principal advantage of this plan was the regular compression obtainable without the employment of skilled labour. It would be well to complete the compression by means of a steam roller; the plan is simple, and will be necessitated by the extension of this kind of work. After ramming, and previous to the cooling down of the material, compression was generally equalised by a heavy roller. This operation was easy when rails were employed, as then the roller could not penetrate beyond a certain depth, but it became less so when the spreading of the material was continuous. Going too early on the still hot surface of the compressed powder with the heavy roller causes it to fly and tears it. Latterly, a roller composed of several sections placed on the same axle has been tried with success. When the surface containing an excess of heat mounts the narrow spaces between the different sections of the roller, just as it is displaced by the passage of a carriage, the surface is crossed and recrossed by the roller.

Compressed asphalt is the best roadway for bridges, on account

of its lightness, only a thickness of a few inches being required. With asphalt for a roadway there is no noise, no jarring of carriages, no street mud, and consequently no dust. Being impermeable, it does not absorb organic matters, the decomposition of which is so noxious to the public health of large towns; and in this respect it is better suited for narrow and damp streets than for wide thoroughfares, to which it has hitherto been specially devoted.

Early Applications of Compressed Asphalt.

In 1858, three sides of the Palais Royal, Paris, comprising an area of 3,000 square mètres (3,588 square yards), were laid with compressed asphalt. The material was brought to the site in the state of rock crushed into small pieces, and was heated and powdered by decrepitators; the concrete was 5·9 inches thick, the asphalt was 2·4 inches thick in the Rue St. Honoré and the Rue de Richelieu, and 2 inches in the Rue de Valois.

In order to overcome the hesitation of the city engineers, the company was obliged to propose a combination of payments by annuities, which were to include maintenance. The entire expense to the town of Paris was fixed at 20 francs per square mètre (say 13*s.* 3*d.* per square yard), payable by annuities of 4 francs during five years.

Success was complete in spite of an unpropitious season; and in the following year the engineers proposed that the Rue des Petits Champs should be paved in the same manner. This street had to be repaved for its entire length of more than 1,000 yards, on account of the construction of a large drain; but the circumstance was unfortunate. The street had been occupied by drainage works in the fine weather; and it was not until the month of October that the roadway could be begun, and then on a soil newly filled in to a depth of 10 to 13 feet. A bed of concrete only 4 inches thick was laid down, on which was superposed a layer of 2 inches of asphalt. The work was carried on during the months of November and December in rain and snow; and the street was opened for traffic on the 1st of January. Cracks immediately appeared, which completely checked the further extension of asphalt roadways. However, the experiment in the Palais Royal continued to give the best results; and as the same materials had been used, it became evident that the true causes of failure were the settling of the soil and the constant wet during the process of laying. Repairs were undertaken of each damaged

part in succession, and at the return of the fine weather all the evil had been remedied. The chief engineer in charge of the roadways declared this trial more satisfactory than the previous one, inasmuch as it proved that the material could be repaired extensively without stopping the traffic of the street. This work, which was carried out without any special conditions, was paid for at the rate of 15 francs the square mètre (say 10*s.* per square yard), including the concrete, estimated at 2 francs (1*s.* 7*d.*). This price was to serve as a basis for future proposals for repairing streets; and the examination of the plans by the engineers of the town of Paris was required by the Prefect. Despite the fact of the first experiment having been made on a loose subsoil, the company shortly afterwards received orders to repave on the same system the Rues Richer and Petites Ecuries, in which the construction of sewers had necessitated such deep cuttings that several foundations had settled, and the houses had to be rebuilt. Unusual precautions were taken to consolidate the soil. The disintegration of the asphalt had thus been much less than in the case of the Rue des Petits Champs; but repairs were more frequent than in other places where the foundation was solid.

Compressed asphalt, amongst other asphalts, was likewise laid down in the Rue Buffon, near the Museum of Natural History. In this case the asphalt rock was comminuted by means of steam.

About the year 1865, the engineers proposed to substitute compressed asphalt for granite sets to the extent of 100,000 square mètres (24·7 acres), to be executed in three years and paid for in five years. This work was begun in 1867, and was arrested in course of execution by the war of 1870. Here trials were first made with other rock than the Val de Travers, which had hitherto been exclusively used for compressed work. Seyssel rock was laid down on that part of the Rue de Richelieu comprised between the Boulevard and the Bourse, one of the busiest streets in Paris, and has answered perfectly. As in other roadways, the concrete was 4 inches thick and the asphalt 2 inches thick. The use of pure Seyssel rock was continued at the Place Louvois and the streets adjacent, with the same success.

Besides replacing granite sets, asphalt has been used to form crossings for foot passengers, in bands from 10 to 15 feet wide. Sometimes the asphalt is applied directly upon the hard macadam, sometimes upon prepared concrete. The crossings are paid for at the same rate as the larger surfaces, only an extra sum is allowed for repairs at the points of contact with the flints, where the wear and tear is much greater than that of ordinary asphalted roads.

In some places mixed roadways, composed of macadam in the middle and asphalt at each side, have been introduced. The point of contact with the rough stones is found to be perfectly supported by the asphalt edge, and the wheel traffic has no deleterious effect. This has been carried out in the Rue Royale, Boulevard de Sebastopol, Cours de Vincennes, and the Avenue de la Grande Armée, in Paris; and at Brussels the same system has been employed in the new boulevard of La Senne, only in the latter place granite pitching replaces macadam.

Compressed asphalt, moreover, has been successfully applied for courtyards and the interior of houses, where the thickness need not exceed 1¼ inch, as the duration appears to be unlimited. In Paris, the courtyards of the Grand Hôtel, the Hôtel de Louvre, the new Opera House, and of a large number of private establishments, amongst others, the Jockey Club and the Rue Scribe, are thus treated; and horses never stumble in such instances, for the asphalt is always kept clean.

The only objection that has ever been made against asphalt roads is that horses slip, and this reproach is only relative. In point of fact, asphalt is much less slippery than stone or granite, but its surface, being without joints, offers no resistance when a horse stumbles. How little slippery asphalt really is may be noticed after the washing effected by heavy rain. The fine dust deposited from the atmosphere, mixed with the staling of horses, gets spread over the surface by the street sweepers. It adheres closely to the asphalt as long as dry weather lasts, and cannot be removed by brooms. Essentially hygrometrical, it will absorb as much as ten times its volume of water. Therefore under the influence of the slightest humidity it begins to swell, and the thin pellicle is solved into a layer of greasy mud, which interposed between the horses' shoes and the asphalt, causes slipping. A simple precautionary measure is all that is needed, viz., to wash the asphalted surfaces every morning during wet or damp weather. The principal cause of slipping would thus disappear, and with it a good deal of prejudice against asphalt.

Wear and Tear.

The effect produced by wear and tear on asphalt is so trivial, that asphalt might almost be said to be imperishable, so long as no other cause than the friction of wheels occurs to alter its working conditions. On asphalted crossings in macadamised roads the wear and tear is rapid. In a few years the original thickness

of $2\frac{1}{2}$ inches is reduced to $1\frac{1}{2}$ inch, and finally to $\frac{1}{2}$ inch; but in streets of ordinary circulation the annual wear and tear is inappreciable. This is evidently owing to the malleability of this body, which yields under a heavy load without being crushed.

Disintegration results most frequently from a singular phenomenon. After the asphalt has been laid and subjected to traffic for a short time, fissures appear on the surface, in places forming an endless network. Eventually the horses' hoofs remove small pieces, leaving holes. The reason of this is that parts perfectly good on the surface are fissured underneath, and that the fissures form nodules. No satisfactory explanation of this fact has been given. Greenish tints, found in fissures over earth blackened by gaseous emanations, have induced the belief that escaping coal gas was the cause; but chemical action would tend to pulverisation and not to nodulation; moreover, the effect is produced on parts free from such escapes of gas. This appearance is mostly noticed in work carried out during wet weather. When powder heated to 260° to 300° Fahr. is spread on a damp surface, steam is generated, which would permeate the whole if compression did not cause cohesion of the molecules on the surface, and force the watery vapour to localise itself, dividing the asphalt only to a height proportionate to the amount of humidity in the soil and the rapidity of the compression. The surface is always well compressed; and where the upper layer joins the nodulated part it is distended by the steam. This is the only cause of disintegration which can escape the eye of the engineer, and it can be avoided by care in laying.

The other causes which may be traced to deficient aggregation of the molecules are discovered either during the work or by the first vehicle which crosses the road. Deficient aggregation may arise from two circumstances; either the powder is too cold when employed, or it has been overheated. Overheating asphalt renders it as inert as sand. Another cause of deterioration, though rare, is the use of asphaltic rock too rich in bitumen. When this is the case, the compressed asphalt forms waves underneath the wheels of vehicles, sometimes longitudinal with the footways, at other times transversely thereto.

Maintenance.

The maintenance of asphalted roadways has engrossed the attention of engineers since asphalt has been substituted for granite. The advantages of asphalt as regards simplicity of application, cleanliness and facility of cleansing, pleasing ap

pearance, and in many cases prime cost, are patent. Time and extended use alone can show whether this kind of road will last longer and be less costly than granite.

In Paris compressed asphalt had to compare with macadam and other systems of paving in stone, porphyry, granite, red sandstone, flags, cubes, &c. The advantage of less cost for repairs over macadam was incontestable. As regards paving stones, the difference was much less marked. A single estimate would scarcely suffice; but, the authorities of Paris alone possessing the data for making the calculation of the cost of maintenance of paving stones, it was necessary to proceed by induction. About twenty years ago the average maintenance of granite causeways was about 50 centimes the square mètre (4*d.* per square yard). The traffic having trebled, the needs of the public having increased, and the materials employed costing more, it was thought reasonable to ask double this price for a system offering so many advantages over paving stones; thus the Compagnie Général des Asphaltes contracted, in 1868, to keep roads in repair at the rate of 1 franc the mètre per annum (8*d.* per square yard), which price included an obligation to renew every year one-tenth[1] of the surface over five years old. This price was not arrived at by calculation alone; it was not possible that it should be, as the works already executed included the cost of experiments imperative with new works. Moreover, the large proportion of asphalted roadways being in streets where the traffic was heavy, did not admit of making a reliable comparison with the average cost of repairs of the roadways in the rest of the city, which included many streets with little traffic.

The Author is therefore of opinion that where the work can be carried out under favourable conditions, and where the majority of the streets are paved with this material, town councils need not pay 1 franc per mètre (8*d.* per square yard) for the maintenance and renewal of the roads. It is probable that for a large surface the average would be inconsiderable, and thus allow towns of secondary importance to procure for their inhabitants the advantages of roads paved with compressed asphalt.

Cost Price.

The value of the raw material is too great, and the cost of transport is too important, to enable a price to be quoted without specifying the locality where the material is to be employed; but

[1] Now one-fifteenth part.—Note of Translator.

the quantity of raw material necessary for covering a given surface can be given, and thus every engineer can ascertain the price by adding the cost of transport to that of purchase.

The specific weight of asphalt being 2·2 to 2·3, the theoretical weight of 1 cubic mètre will be 2,300 kilogrammes (3,874 lbs. av. per cubic yard), and that of 1 square mètre, 1 centimètre thick (0·394 inch), 23 kilogrammes (50·7 av. lbs.), which in practice may be considered 25 kilogrammes (55·1 lbs. av.). Works employing say ten men, most of them labourers, a 25 to 30-HP. engine, and fitted with the necessary apparatus to avoid useless labour, can receive, crush, pulverise, and heat, in a day of ten hours, 30 to 40 tons of asphalt. The coal required for heating may be about 2 tons. The carts should take one horse-load, so that not too much material may arrive at the work at one time. The time of transit may last an hour without inconvenience.

For laying down, supposing the concrete ready and the workmen only occupied with the asphalt, the work in full swing, the job extensive and regularly supplied with hot powder, the labour costs little; a gang of ten to twelve men can complete 50 square mètres (538 square feet) in an hour. But for small undertakings the price of labour rapidly increases in proportion, being largely absorbed, for instance, in the cost of making cuttings for gas and water works, and in filling up depressions of the soil.

As regards the relative value of the only two asphaltic rocks used at present in laying compressed asphalt roadways, the Val de Travers limestone has not so close a grain, is softer, and is more regularly impregnated with bitumen than the Seyssel rock; but no engineer could conscientiously say that the Val de Travers is better than the Seyssel asphalt. The former may be safer in the execution of a work not subjected to supervision; the latter offers greater guarantees of good execution, because more care is required in the work.

III.—Asphalt Mastic.

It was under the form of mastic, designated by D'Eyrinys as "natural cement," that asphalt was first employed in public works in modern times. The slowness with which this material has made its way in the construction of houses can only be attributed to the mode of its employment necessitating heavy plant, and skilled workmen, who require a long apprenticeship.

Mastic asphalt has all the qualities of cement for uniting building materials, but the Author confines his attention to its application in making footpaths.

It has been already stated that bituminous limestone heated to between 212° and 300° Fahr. loses its consistency and is reduced to powder. If the heating be increased the powder does not melt, but the bitumen is evaporated, leaving the limestone, when at red heat, perfectly pure. If, however, on attaining a temperature of between 390° and 480°, a small portion of free bitumen be added the asphalt melts. This property leads to a complete transformation of the bituminous limestone; after melting it is no longer possible to reconstitute the asphalt and bitumen. Analysis gives bitumen and white limestone, but not bituminous limestone or asphalt. Moreover, of two pieces of asphalt rock, one containing 5 to 6 per cent. of bitumen, the other 15 per cent. of bitumen, the latter will not melt alone, whereas it will suffice to add from 7 to 8 per cent. of pure bitumen to the former to induce fusion and make a mastic, though less rich in bitumen than the first; but it will not remelt without a fresh addition of bitumen. It would thus appear that pure bitumen acts as a flux.

BITUMEN.

Bitumen is widely disseminated, occurring in the products of decomposition of all organisms. That first employed for pharmaceutical purposes was evidently extracted from the asphalt itself. There existed an affinity between the two elements of fusion, and the mastic obtained would be of superior quality, but the process must have been very costly, on account of its necessitating distillation and of its wasting a large quantity of bituminous limestone. At Seyssel, for a long period bitumen was employed, produced from the bituminous sand of the soft greenstone which crops up frequently on the banks of the Rhone. Later a very rich seam of this stone was discovered at Bastennes in France.

The process employed for separating the bitumen from the sand is still the same as that described a century ago by D'Alembert in his Encyclopedia. The bituminous sand is poured into a boiler containing boiling water; at this temperature the bitumen becomes liquid and separates from the sand; being lighter than water, it rises to the surface, whereas the sand sinks to the bottom. This primitive mode answers perfectly so long as the rich sand is found at the surface and near roadways, but it becomes too expensive if the sand has to be carted to a distance.

Repeated attempts have been made to utilise the quality possessed by sulphuret of carbon of dissolving bitumen. An establishment was erected in Auvergne, where a great deal of sand rich

in bitumen was found. At Naples more extensive experiments were made with an apparatus which treated at the same time sulphur ore; but the results, though interesting, were too expensive to admit of the establishment of works. They showed, however, the expediency of continuing trials in this direction. The great drawback is the high price of sulphuret of carbon, combined with its great volatility, which causes loss from leakage.

For a long time Seyssel mastic was made with pure bitumen extracted from the soft stone, and for remelting the mastic when laying the footpaths Bastennes bitumen was obtained by the washing process as long as the seam lasted.

The chief quality required for bitumen used for footpaths is the retention of the pasty appearance under the influence of great variation of temperatures.

Indigenous Bitumens.

At first indigenous bitumens were tried, but the supply from Judæa was limited, and the price too high. Here it may be said that gas-tar is decidedly the worst form of bitumen for paving purposes, as it passes from the dry to the liquid state, and *vice versâ*, according to the season, and is very brittle.

Trinidad Bitumen.

Indigenous bitumens being found also in the state of dry pitch mixed with earth and water, efforts have been made to utilise those found on Lake Brea in the Island of Trinidad.

The spring of indigenous bitumen must have been considerable, for the water has almost disappeared from the lake, the bitumen forming a mass traversed only by a few narrow channels. The bitumen constantly springing up has overflown the banks, and, following the fall of the earth, has spread out seaward, forming a regular jetty, protecting vessels during their lading. Under the ardent sun of these latitudes the viscid matter partially evaporated, partially mixed with dust, has become solid on the surface, and forms the raw dry pitch exported to Europe. The process of removing 25 per cent. of foreign matter is effected by pouring into open boilers, which should not be exposed to naked flame, a given quantity of shale oil; as the oil gets heated, raw bitumen to about double the weight of the shale oil is added. The cooking with a steady fire lasts about eighteen to twenty hours. After sundry strainings and decantings, the purified bitumen is cooled and put into casks. This bitumen serves to replace that extracted

from the soft stone and sand when the operation is properly conducted, and the pitch is of good quality, but it also costs much less. The process of preparation is a delicate one, and the despatch in casks allows of fraud.

Manufacture of Mastic.

M. Malo, in his treatise, gives full explanations concerning the manufacture of mastic, which will not be further referred to. The material is sent to the places of consumption in blocks or cheeses 1 foot in diameter and about 4 inches thick. Like rock asphalt, heated alone, mastic does not melt, but only becomes soft; if the heating is continued it loses its bitumen and leaves a coal-like residuum. To endure remelting a fresh quantity of pure bitumen must be added.

Although it is only intended to refer to asphalt mastic in its relation to footpaths, it may be permitted to mention its application, under similar conditions, as a covering for vaults, its elasticity and malleability guaranteeing it against the cracks and fissures so often complained of in cement and mortar coverings.

The employment of asphalt mastic for footpaths is considerable. It is probable that, by illicitly using it as mortar, the idea arose of mixing sand with it. The result has proved excellent. No chemical union takes place between the mastic and the sand, but the cohesion is so complete that the fracture of sanded mastic will show the simultaneous fracture of the grit. Moreover, the non-susceptibility of sand to the heat of the sun compensates for the susceptibility of the mastic; and, as the quantity of grit or sand may reach 60 per cent., the price of the work can be proportionately reduced. The conditions necessary for the laying of mastic are to prepare it with the least possible quantity of bitumen, and to lay it as hot as practicable.

Laying Down.

For many years the apparatus for remelting the mastic consisted of boilers of a primitive construction of wrought iron, fitted with stove chimneys: but the use of these boilers in the streets was too inconvenient in such important works as those of the city of Paris. It became therefore necessary to contrive other means, and in 1858 the mastic was prepared in large stationary boilers in depôts, and delivered hot to the works in portable boilers, which could be heated and stirred during transport. The fixed boilers for preparing the sanded mastic are similar to those used for ordinary mastic, except that they are provided with a bell-shaped

mouthpiece to allow of the hot material being poured into the portable furnaces. The layer of mastic possessing no resistance in itself, and being simply a carpet, necessitates the consolidation of the soil, which is ordinarily done by concrete, the surface of which is floated with mortar.

Price of Work.

As with compressed asphalt, it is difficult to fix a price without knowing the locality of the work to be executed, on account of the cost of transport. The cost can, however, be readily arrived at as follows:—The preparation of 1 ton of sanded mastic requires 13 cwt. of pure block mastic, 2 qrs. 12 lbs. of bitumen, 7 cwt. of grit or sand washed and dried, and 2 cwt. of coal. A workman can easily prepare 3 tons of material in a day of twelve hours.

The specific weight of mastic being about the same as that of asphalt and sand, the weight of 1 cubic mètre of sanded mastic will be, say, 2 tons 6 cwt. (1 ton 15 cwt. per cubic yard), and consequently a layer 1 centimètre (0·39 inch) in thickness will give, theoretically, about 50 lbs. weight per square mètre, or, practically, 56 lbs. per square mètre (46 lbs per square yard).

It requires a long apprenticeship before the workman can obtain a layer of uniform thickness. A skilled workman can, when the surface is well prepared, and the hot mastic supplied continuously and well poured by his assistants, lay from 120 to 150 square mètres (140 to 180 square yards) in a day, 15 millimètres (0·6 inch) thick. As an average, 120 square mètres can be obtained by a gang of three men, *i.e.*, one spreader, and two bringers. When, on the other hand, the workman is obliged to prepare the mastic in the old pot boilers himself, he requires an assistant for each boiler, and the preparation takes four to five hours, without counting the laying and pouring. Under such conditions, a gang of three men will only lay 55 square mètres (66 square yards) a day.

The thickness generally used for footpaths and public buildings is 15 millimètres, equal to 35 to 38 kilogrammes of sanded mastic per square mètre (64 lbs. to 71 lbs. per square yard). For railway stations, where there is goods traffic, 2-centimètres thickness of mastic, or 45 kilogrammes per mètre (83 lbs. per square yard), is generally adopted; and for passages and entrances subject to heavy carriage traffic about 4 to 5 centimètres (1·6 inch to 2 inches) thickness is used.

Roadways or Causeways.

In Lyons mastic has been applied to several roadways, chiefly in the small, narrow, damp streets and alleys, for sanitary reasons;

and as the traffic is trifling, the repairs have been few. Some of these roadways are twenty years old.

The trials in Paris have given much less satisfactory results. The failure may perhaps be attributed to the mixture of two bodies —asphalt and grit, the resisting powers of which are essentially different. When, owing to the wear of the mastic, the grit appears on the surface of the roadway, it is soon displaced, leaving the socket exposed. This is a cause of disintegration, which, often repeated, soon leads to the breaking up of the roadway, and the drier the mastic, the quicker the destructive action. For roadways mastic asphalt has been generally abandoned in favour of compressed asphalt rock, which is homogeneous in texture.

Duration.

The duration of asphalt beds has, unfortunately, never been stated with sufficient accuracy, taking into account the modifications caused in laying gas and water pipes; but it is certain that asphalt mastic on footpaths will bear for a long time a considerable traffic of passengers.

In Paris, under the arcades of the Rue de Rivoli, of a mastic sidewalk laid in 1845, and which was not relaid until 1868, there remained a thickness of 3 to 4 millimètres (0·12 inch to 0·16 inch), which was removed in large sheets. Again, in the Place des Célestins, at Lyons, asphalt mastic laid in 1840 still exists in spite of heavy traffic.

In ordinary conditions, a duration of fifteen years may be reckoned upon. This basis has been adopted for a system of maintenance for more than twenty years in Paris for the footpaths. Against an annual payment of a fixed sum per mètre, the contractor undertakes the repair of the paths, and renews every year one-fifteenth part of the existing surface. Thus the normal thickness of the layers of mastic is always maintained.

Imitation Asphalt.

By analysis asphalt mastic gives limestone and bitumen. By mixing heated limestones and gas-tar, a material having some of the properties of asphalt mastic has been obtained, just as stucco has some of the properties of marble.

The first trustworthy trials gave a bad result, and the employment of imitation asphalt was proscribed in all specifications of public works: but as detection is difficult, frauds soon took place on a large scale. As the great economy in imitation asphalt is in the

saving of carriage, the proof of transport from the mines will prevent this in many cases. Imitation asphalt is applicable in certain rare cases, great care being taken in its preparation; but it should never be used for footpaths or in places exposed to great variations of temperature. Bitumen, artificially combined with limestone, is unable to resist the tendency to disintegration inherent in those bodies, the components of which have been subjected to unknown conditions of temperature and pressure.

At present the formation of roads and footways is the principal application of asphalt. When engineers know the material and can rely upon its special qualities, the field of its employment will be considerably extended. Thus, in the construction of buildings exposed to floods, a layer of asphalt mastic under the foundations, and a narrow wall of bitumous concrete all round up to the extreme water-level, will protect the building from damp.

A bed of rubble smeared well with mastic at the point where the masonry rises from the surface of the ground will prevent the rise of damp by capillary attraction.

Blocks of concrete for the construction of marine jetties and piers, furnished with an exterior layer of bituminous concrete 4 to 5 inches in thickness, may be made of ordinary materials. The asphalt mastic opposes its elasticity to the percussive action of the shingle, and its bitumen to the decomposing action of marine salts upon limestones and cements. Several such blocks, of 13 cubic yards, have existed for more than ten years at the Pont de Graves, near Bordeaux, and justify the Author's assertion.

MEMOIRS OF DECEASED MEMBERS.

MR. PRICE PRICHARD BALY was born at Warwick in the year 1819. He was educated at the grammar-school of his native town and at Clapham Grammar-school, of which the Rev. Charles Pritchard, now Professor of Astronomy at Oxford, was then the head master. In 1838 Mr. Baly became a pupil of the late Mr. I. K. Brunel, in whose office he made the calculations for the Clifton and the Hungerford suspension bridges, and he subsequently acted as Resident Engineer for the construction of the latter. While thus employed, his attention was directed to the utility of baths and wash-houses for the labouring classes, and with the ardour of an active philanthropy he gave his time and professional services to the original establishment, and the subsequent extension of many of these beneficial institutions in London and various provincial towns, assisted architecturally by his intimate friend Mr. Charles Barry. In 1845 Mr. Baly undertook his first work abroad, superintending the construction, from the beginning to its completion, of the railway from Manage to Wavre in Belgium. He was afterwards appointed Engineer of the Great Luxembourg railway, when only a fourth part of that line was finished; and in 1857 and 1858 he was engaged in designing railways in Holland and in Russia. In the latter year he was employed by the Russian Government to examine the ground between the Black Sea and the Caspian, with a view to the construction of railways to connect those important parts of the empire; his surveys resulted in his reporting favourably on the practicability of carrying lines through that difficult country; and his ability to cope with the obstacles which nature presented to engineering labours obtained the warm support and the cordial co-operation of Prince Bariatinsky, the Governor of the Caucasus. Mr. Baly subsequently laid out the line of railway which has been for some years in operation between Tiflis and Poti; and until the year 1869 he was almost exclusively employed by the Russian Government, with a large staff of engineers and assistants, in designing various public works in the Caucasus. They comprised surveys and designs for ports at Soukhoum-Kali, and Poti on the Black Sea, and at Bakou on the Caspian; and also of works for irrigation and sewage, and

for piers. This latter occupation led to his devoting much attention to the subject of the construction of harbours generally; and he originated a plan of detached open-work piers for the formation of ports, where natural facilities are not afforded, known as Baly's Octopus System of Piers.

He had completed designs for a port at Madras, and was engaged in studies of similar works for the construction of piers at Bournemouth and Folkestone, and at Ostend and Blankenberg, when his too early death removed him from a circle of professional and private friends, who deplore the loss of one whose courteous manner, kindly nature, and genuine honesty, together with a mind stored with knowledge, will ever render him dear to memory. Mr. Baly was singularly gifted with the power of applying mathematical science to practical engineering, and was of most industrious habits, but endowed with greater mental than physical power. He was elected a Member of the Institution of Civil Engineers on the 6th of April, 1852, and died on the 5th of September, 1875.

In 1863, the question of the reconstruction of Westminster Bridge being under consideration by a Committee of the House of Commons, Sir Charles Barry sought the assistance of Mr. Baly to devise a mode of construction in iron, by which the roadway over the arches should be as thin as possible, and the bridge as level as practicable. The evidence founded on this advice influenced, it is believed, the adoption of the plans eventually carried out. Subsequently Sir Charles Barry occasionally asked the opinion of Mr. Baly, for whom he entertained a high respect, on matters referring to any peculiar adaptation of iron in structures.

MR. JAMES DEES, of Whitehaven, and Riverdale, near Bellingham, Northumberland, was one of those self-trained engineers whom talent, natural aptitude for the work, combined with great application and perseverance, brought in early life into contact with civil engineers; and by the exigencies of the times he was raised to the surface during the railway mania, when the demand for civil engineers far exceeded the supply of those regularly trained in the profession.

The only child of parents in a comparatively humble position, he was born at Meldon, near Morpeth, in March 1815. In early life he began business as a builder and contractor, and, whilst so engaged, he along with one or two others successfully carried out a contract for the construction of the stone railway bridge over the river Tees at Croft, near Darlington, designed by Mr. Henry

Welch. This was a skew, or oblique bridge, of three spans of 60 feet each, with an angle of obliquity of 50°, to carry what was then called the "Great North of England railway." The foundation-stone was laid in May 1838, and the work was completed in the summer of 1840. Here Mr. Dees and his partners adopted the principles of operation advanced by Mr. Peter Nicholson in his work on the "Construction of the Oblique Arch," the stones being dressed to templates made according to the formulæ laid down in that work.

In 1845 Mr. Dees removed to Cumberland, where, as Assistant Resident Engineer, he superintended the making of the Whitehaven and Furness Junction railway under the Stephensons. On the completion of that line he was appointed Engineer to the Company, and shortly afterwards was also chosen for the same office by the Whitehaven Junction Railway Company. In 1851 he made the tunnel, ¾ mile long, under part of the town of Whitehaven which connects these two railways. This was a work of some difficulty, owing to the loose nature of the ground and the fact that it was disturbed by old colliery workings. In 1853 he was appointed Engineer to the wet dock at Maryport, which he constructed to the entire satisfaction of its promoters, and in the same year received a similar appointment from the Whitehaven, Cleator, and Egremont Railway Company, whose line was projected and formed under his superintendence. Having become, a few years later, connected with one of the largest and most lucrative hematite iron-ore mines in the neighbourhood of Whitehaven, Mr. Dees, finding himself in the possession of ample means, retired from the active exercise of his profession. He took a prominent part in public matters, and was for some years captain of the Whitehaven Volunteer Artillery Corps, and a trustee of the town and harbour of Whitehaven. He was also at the time of his death a Governor of the Whitehaven Infirmary; a Director of the Whitehaven Shipbuilding Company, and of the Whitehaven, Cleator, and Egremont Railway Company; Deputy Chairman of the Solway Junction Railway Company, and a Justice of the Peace for both the counties of Cumberland and Northumberland. In later years repeated attacks of gout somewhat crippled his energies, and he spent much of his time at his country mansion of Riverdale, where he died on the 19th of September, 1875, from internal hemorrhage, after a short illness, highly esteemed in both counties and throughout the North of England, where he was best known.

Mr. Dees was elected a Member of the Institution of Civil Engineers on the 7th of February, 1854.

MR. FREDERICK EAST was born in London in the year 1819. He received some training as an architect under Mr. Thomas Finden, and afterwards became a pupil of the late Mr. I. K. Brunel. He was subsequently employed for some years on railway works in England by Mr. Brunel, Mr. Fowler, and Sir Morton Peto. In 1859 Mr. East was, on the recommendation of Sir Morton Peto, appointed a "second class" Engineer on the Punjâb railway; and in May, 1860, when the post of Chief Engineer became vacant, he was selected to officiate in that capacity by Mr. Raeburn, the agent, a nomination approved by the Government of India, and he continued for some months to act. The manner in which his duties were discharged on this occasion was characterised by the Chairman of the Company as satisfactory to the directors; and as the Punjâb Government also expressed a favourable opinion of Mr. East's services, he was promoted to be a "first class" Engineer. He resigned this appointment in the beginning of 1862, and returned to England. In June, 1863, he was appointed an Executive Engineer of the Madras Irrigation and Canal Company, and was sent to Nellore to mature a scheme for canals of navigation and irrigation through that district, from Somaswaram to the sea; and this work he completed in 1867. The Chief Engineer, in reporting on Mr. East's scheme, observed that "it bids fair to stand criticism of all kinds, and to stand as the best hitherto proposed;" but it was not carried out, owing to the financial position of the company. From this time until 1870, when he left the Company's service, he was engaged in the construction of works in the Cuddapah and Kurnool districts, and on surveys and investigations for large reservoirs proposed to be constructed in the Mysore district. At the end of 1870 Mr. East went to Kattyawar, and for about eighteen months was engaged by the State of Bhownuggur in designing and executing engineering works of considerable magnitude, and of a kind that had not been before attempted in that or any of the neighbouring states. The most important of those carried out was the supply of water to the town of Bhownuggur by means of masonry dams across two rivers, a large reservoir, and subsidiary works. As the supply of water to the town was an urgent want, the work was conducted with great rapidity, and this entailed extra anxiety and labour, under the pressure of which Mr. East's health was seriously injured. In 1872 he returned to England, and, his strength gradually failing, he died at St. John's Wood on the 15th of December, 1875, and was buried at Kensal Green Cemetery.

In addition to his skill as an engineer, Mr. East was a man of considerable natural ability and culture outside his profession. He

devoted much of his leisure to music, sketching, and literary composition; and these attainments, added to his lively and agreeable conversation, made him a most pleasant companion. He was also invariably kind and considerate to those with whom he worked. He was elected a Member of the Institution of Civil Engineers on the 5th of December, 1865.

MR. THOMAS EMERSON FORSTER, who died at Ellison Place, Newcastle-on-Tyne, on the 7th of March, 1875, was well known during nearly half a century, first as an able and successful 'viewer' or manager of collieries in the districts near the river Tyne; afterwards, in addition to greatly extended practice as a mining engineer, he was consulted as to the general management of large mining concerns, and by his probity, practical skill, and intelligence, he attained high eminence in his profession. One of his intimate contemporaries described him as having been the hardest worker he ever knew, and few, if any, have exceeded him in the skill and vigour with which he applied himself to matters connected with practical mining. His ambition was to be "a thorough pitman," by which is implied the possession of every faculty, bodily and mental, that conduces to success in the practical working of coal-mines.

The birthplace of Mr. T. E. Forster was Garrigill, a small and retired hamlet on the left bank of the river South Tyne, only a few miles from its source on the eastern slopes of the mountain of Cross Fell, in Cumberland. This part of the county is well known as the Manor of Alston Moor, and is essentially a mining district, containing valuable lead-mines, with some inconsiderable beds of coal, which present a conspicuous feature in the aspect of the country. There is little doubt that the future profession of the subject of this memoir was influenced by circumstances surrounding his birthplace. Mining was the chief occupation of the inhabitants of this and adjacent places, and some of the family connections of young Forster were remarkable for advanced skill and knowledge. One of these, a cousin of his father's, was Westgarth Forster, whose name became a sort of household word among North of England lead-miners from his having, in 1816, published a book called "A Section of the Strata from Cross Fell to Newcastle-on-Tyne," of which a second and greatly improved edition appeared in 1821. Another connection of the family named Westgarth had, so long ago as 1771, gained high commendation

for practical skill from no less an authority than Smeaton,[1] who for a time had charge of the mining district of Alston, and whose great, though by no means greatest work—the Nentforce Level—was being driven during all the years of young Forster's youth, at a distance of only 3 or 4 miles from his birthplace.

Mr. Forster, senior, having removed to Hebburn, near the mouth of the river Tyne, his son received a good ordinary education, and at the age of fifteen was apprenticed to Mr. Wade, one of the owners of Hebburn Colliery—of which the resident viewer at that time was Mr. Matthias Dunn. The head viewer was Mr. John Buddle, then, and for many years afterwards, known as the most eminent colliery viewer in the North of England. Of the opportunities thus afforded, young Forster made good use, and he had the further advantage of instruction from his relation, Westgarth Forster, to whom he always acknowledged a deep debt of gratitude. As a youth, he was strong, active, and willing, qualities which gained him the favour of influential friends. When little more than twenty years of age, he was appointed resident viewer at Walker Colliery, in Northumberland, in the immediate vicinity of Wallsend, the produce of which colliery was so famous. Two years afterwards he took a highly responsible position at Hetton Colliery, in the county of Durham, and in 1831 removed to Haswell, where he resided many years in a house built purposely for him, and in which he was as hearty and hospitable in his leisure hours as he was diligent in all his duties. These, it may be observed, were, even under ordinary circumstances, of a very arduous character, but the difficulties in sinking one of the principal shafts were greatly increased by an extraordinary influx of water from sand-beds lying under the magnesian limestone, so that, notwithstanding every exertion, it was deemed desirable to abandon the shaft and make a winning at another place. The position of chief viewer, which he now held, increased his field of duty, without in any way diminishing the actual labour for which he had been conspicuous. Rising at four in the morning was a usual practice, and his occupations day by day might justly be described as indefatigable.

When the wooden wagon-ways or railways, so long in use in the North of England colliery districts, were superseded by iron rails, and the modern system of locomotion came into use, Mr. Forster took an active part in laying out and constructing the Durham and Sunderland railway, and became connected with various collieries and other works, amongst which may be named

[1] *Vide* Reports of the late John Smeaton, F.R.S., vol. ii., p. 376.

the Belmont, Shincliffe, Shotton, Byers Green, and Scremerston collieries. He became Consulting Engineer to the Earl of Lonsdale, to Lord Boyne, and to other large owners of mineral property, and was connected with many of the most important and extensive mining works in the North of England. He became a Member of the Institution of Civil Engineers on the 16th of February, 1836, and was afterwards, from 1866 to 1869, President of the North of England Institute of Mining Engineers. Of these and other matters, of which the details possess chiefly a local interest, many particulars are given in an excellent Memoir in the pages of the Transactions of the last-named Institution.

The duties of a colliery viewer, in which Mr. Forster was so largely engaged, were such as none but the most vigorous and laborious men could execute. Sometimes at midnight, or at the early hours of two or three o'clock, he was subject to be called upon to travel many miles, to descend deep pits, to traverse underground works, and, not unfrequently, to penetrate into parts of a mine where nothing but the most careful judgment could preserve him from extreme risk of explosion or other accident. The commander, as it were, of many thousands of miners, he not only directed their labours, but gained their friendly confidence. In the mine he was thoroughly at home. He affected only such habits and modes of speech as were perfectly understood by the pitman; and to this peculiar tact his usefulness and success were in a great measure owing. In dealing with those of elevated rank, a respectful deference was never allowed to interfere with the most plain and freely spoken expression of opinion; and thus he maintained at all times a consistency of character, and a large amount of influence with all parties he met, or for whom he was concerned in professional business.

In 1846 Mr. Forster settled at Ellison Place, Newcastle-upon-Tyne, and here the remainder of his life was spent. Until about two years before his death he retained much of the activity of former years, though less called upon for extreme bodily exertion. He aimed steadily at improvement, and pursued with enthusiasm plans which appeared likely to be of use; he endeavoured to keep pace with a progress which in all matters of scientific import was more rapid than it had been in any former time. In 1866 he acted as one of the local Commissioners of Inquiry into the Produce and probable future Supply of Coal. His evidence, whether in Parliament or elsewhere, was always clear and straightforward, and if marked by a somewhat urgent manner and local mode of expression, yet it was much more strongly marked by a complete practical knowledge of his subject and by more than usual ability in making himself clearly under-

stood. He may be considered as having been, in his own department of engineering, one of the most earnest practical men who have been connected with this Institution. The work of a mining engineer, however arduous and however diligently performed, is not of a kind to present many salient features to public observation, but not less important, therefore, to the large manufacturing industries of this country and the domestic comforts of its inhabitants are the unseen, and, in a great measure, unknown labours by which large supplies of fuel are obtained from the bowels of the earth. It is, therefore, with more than common interest that an endeavour has been made to do honour to the memory of a distinguished member, who, by untiring industry, by constant adherence to duty, however difficult, and by blending practical skill with scientific research, has left an example worthy of being commended to all Engineers. All honour is due to such men, and accordingly prominence is here given to the name of Thomas Emerson Forster, as having united the special knowledge and practice of a colliery viewer with the general skill and varied experience of the Civil Engineer.

MR. GEORGE HARRISON, son of the late Joseph Harrison, of Birkenhead, was born in Liverpool on the 4th of June, 1815. He served his apprenticeship as an engineer with Messrs. Mather, Dixon, and Co., of Liverpool, and Messrs. Jones, of Newton-le-Willows, on the completion of which he went to France, and became the Locomotive Superintendent, at Paris, of the Paris and Rouen railway, on its opening in 1843; he remained there until his appointment as Locomotive and Carriage Superintendent of the Orleans and Bordeaux railway, which appointment he held until the revolution of 1848 compelled him to return to England. He afterwards became Locomotive Superintendent of the Scottish Central railway and of other lines in Scotland associated with it. In 1853 he was consulted by Messrs. Peto, Brassey, and Betts in reference to the construction of the locomotives for the Grand Trunk railway of Canada. He therefore visited Canada, and, upon his report, it was decided to establish works in England, in preference to Canada, for the purpose of constructing the locomotives and wrought-iron bridges; whereupon the Canada Works were founded at Birkenhead, with which he remained connected up to the time of his death. The great bridge over the river St. Lawrence at Montreal was made at these works, and since the completion of the Grank Trunk railway, works of a gigantic

character have been successfully carried out, under his supervision, for railways in Great Britain, France, Spain, Italy, Portugal, America, India, Australia, and other parts of the world. Mr. Harrison was, for a time, Manager of the Millwall Ironworks, London, and of the Humber Ironworks, at Hull. About the year 1855 he became a Commissioner for Birkenhead, and was the first to propose the introduction of the large saloon steamer at Woodside ferry, on the river Mersey; he never ceased agitating the question at the meetings of the Board until the present splendid class of steamers was placed on the station. The new portion of the great landing-stage at Liverpool was constructed at the Canada Works. When on the eve of completion this stage was destroyed by fire; the anxiety consequent upon this unfortunate accident preyed much upon his mind, he having a great desire to see the reconstruction carried out; however, his health failed before the work was accomplished.

Mr. George Harrison was elected a Member of the Institution of Civil Engineers on the 18th of May, 1852; and he was also a Member of the Institution of Mechanical Engineers. He died in London on the 2nd of June, 1875.

MR. CHARLES INNES SPENCER was the son of Mr. Henry Spencer, of London, and Ann Phyllis, daughter of Sir William Beechey, R.A. Though born in England, his infancy and childhood were passed in France—the latter in Paris—his education being carried on at home, supplemented by lectures on science at the Sorbonne. As a boy, he displayed great power for acquiring languages, five of which he had mastered at the age of eighteen; but it was not until he was twenty years old that, on his removal to Fleetwood, he developed, under the care of his brother, the Mathematical Master of Rossall School, great mathematical powers. On entering as an engineer student at King's College, London, he carried off, in his first year, the second year's scholarship; following his success by winning the third year's scholarship in his second year. He then claimed his Associateship, which was granted by the Council, with a resolution that such an exception should never be made again. On the 1st of January, 1850, he sailed from Southampton, without any prospective employment, to seek his fortunes in India, and was for many months hospitably entertained by the late Mr. Meyrick Shawe, C. S. magistrate at Sylhet. He at length found active work at Serampore under the contractors for part of the East Indian railway, in which position he obtained

much knowledge of the value of different materials, having his hand at everything, from the building of houses on high poles to be above the inundations, to the burning of clay for ballast. This experience was of great use to him when subsequently appointed to an Inspectorship of railway works, a position he selected out of five offered to him within the week after leaving his former employment. His object, however, was not to inspect only, but to work; and as a consequence he soon found engineering occupation higher up the line, and established himself at Chunar Fort, nearly opposite Benares, trying the ground for stone, of which he discovered an excellent quarry, and spending months in the jungle in search of prickly plants, and bringing back from two to three millions of them for the railway hedge-rows. At Chunar, in 1857, he was one of the handful of Englishmen who persuaded the disaffected garrison of the fort that it was advisable to disperse quietly.

At a later date he was appointed Second Engineer of the Allahabad and Jubbulpore line, under Mr. H. P. Le Mesurier, C.S.I.; and here his engineering ability, resources in emergencies, and readiness of invention were abundantly testified. It was on this line that, finding his native workmen unable, or unwilling simultaneously to knock away the supports of the arches, he adopted the plan of resting the ends of the timbers on strong bags of canvas, filled with sand, to be emptied by turning a tap, regularity in this light action being secured by giving time with a flute. The result of his skill and care has been, that on a line crossing many streams and nullahs, no bridge or viaduct has ever failed.

On the completion of the line he was appointed District Engineer, and took up his abode at Jubbulpore. He arranged that when the Governor-General travelled over the line, double parties of men should be stationed at short intervals over the whole way, who, starting north and south, moved on till they each encountered another party coming in the opposite direction. While the railway was under construction he had lived at Ucharah, about halfway between the extremities of the line; and if, from the loneliness of the situation, he was unable to exercise that ever-ready kindness and hospitality he showed to Englishmen, it was still in the same spirit that hundreds of natives were daily fed, in the last famine, from his resources, aided by contributions. In the midst of the duties of his position as District Engineer at Jubbulpore, added to the voluntary duties attached to offices which his good nature forbad refusal, such as Municipal Councillor, Colonel of the Railway Volunteers, President of the Railway Institute, &c., he still found time to attend to improvement of details in railway working, his last inven-

tion being a new system of signalling. His death, which occurred on the 28th of November, 1875, was very sudden and unexpected. It is supposed that the severe shaking he received two or three months before in a railway accident at Kutnee, caused by the parting of a bolt of the cow-catcher, was the primary cause of it. The estimation he was held in, where he was best known, may be judged by the notices in the local journals. One writes: "A competent and learned engineer, a kind and just master, a great mover in public matters, a social and urbane member of society, and, above all, a true Christian—Mr. Spencer was liked by natives and Europeans alike, and his death is being lamented by all." Another writes: "The deceased gentleman was highly respected by all, but more especially by those who had the pleasure to serve under him, as testified by the universal sympathy expressed by both European and native: it would, indeed, be difficult to recall a single instance where he used even a harsh expression to any of his subordinates during the many years he served the East Indian Railway Company; he was ever ready to listen to any just complaint, and was equally prompt in administering redress." Such extracts might be readily multiplied, but these are sufficient to show that by the death of C. I. Spencer the East Indian railway has lost a good engineer; his acquaintance, servants, and colleagues a good friend; his family, a good man.

Mr. Spencer was elected a Member of the Institution of Civil Engineers on the 1st of April, 1862.

MR. CHARLES BLACKER VIGNOLES was one of the oldest survivors of that class of eminent civil engineers who have, during the present century, raised the profession to which they belong to the highest distinction, and have at the same time conferred on their country substantial and enduring benefit. Mr. Vignoles was descended from a family of position in France, some of whose members embraced Protestantism in the seventeenth century, and one of whom, the Sieur de Prades, took refuge in Holland, eventually settling in Dublin at the beginning of the eighteenth century. The descendant of this refugee, Charles Henry Vignoles, father of the subject of this memoir, exactly one hundred years ago, served his country as an ensign in H.M. 43rd Regiment of Light Infantry, known as the Monmouthshire. In 1793 this gentleman—then Captain Vignoles—was stationed in Ireland, where his only son, Charles Blacker, was born, at Woodbrook, in the county of Wexford, on the 31st of May in that year.

The infancy of Mr. Vignoles was spent in the West Indies with his parents, though he was soon destined to be deprived of both; for Captain Vignoles was wounded in action at the storming of Fort a Pietre, on the east side of the island of Guadaloupe, and died of his wounds, his wife (daughter of Dr. Charles Hutton, F.R.S.) surviving her husband only one week. At the death of his parents the child was a prisoner of war, and by way of effecting his release, and doubtless also in consideration of his father's premature death, Sir C. Grey, the General Commanding in Chief of the Forces, bestowed a commission upon Captain Vignoles' infant son, and he was gazetted as an ensign in the 43rd Regiment, and put on half-pay.

He was now claimed by his uncle, Captain, afterwards General, Hutton, R.A., to whom he was surrendered by the authorities of the island. The young officer was afterwards brought to England, and placed by a friend under the care of his grandfather, Dr. Charles Hutton, the celebrated mathematician, then, and for many years subsequently, professor at the Royal Military Academy, Woolwich. There can be no doubt the foundations of a sound and liberal education were carefully laid by this accomplished man, who adopted the child as his own. An incidental proof of the estimation in which Dr. Hutton was held, is furnished by the fact that the father of the late Earl Stanhope bequeathed to his distinguished friend the original portrait in oil of Sir Isaac Newton, which had come into the possession of that noble family. The subject of the present notice inherited from his grandfather this valuable picture, and it was presented by him several years ago to the Royal Society, of which learned body Mr. Vignoles was himself a member.

About the time that Dr. Hutton resigned his professorship, viz., 1807, he seems to have articled his grandson to a proctor in Doctors' Commons, and the usual term of seven years' apprenticeship is mentioned in the indenture. He gained, no doubt, considerable insight into the subtleties of legal procedure during the two or three years devoted to those studies; but it is quite clear that he did not complete his articles, for in his nineteenth year he was a student at Sandhurst, under the care of Professor Leybourne. This must have been a more congenial place than a lawyer's office for one of his lively and active temperament.

Ensign Vignoles' anxiety to see something of actual warfare was gratified by an order to join his regiment in the Peninsula, and he was present in the rearguard at the battle of Vittoria, on the 21st of June, 1813. It is worthy of remark that through this very

region, and over the passes of the Cantabrian Pyrenees, half a century later, Mr. Vignoles constructed a railway from Bilbao to Miranda and Tudela, on the Ebro. The young soldier, now in his twenty-first year, was in the following November transferred to the York Chasseurs; and in January 1814, by the influence of the Duke of Kent, by whom he was favoured with a personal interview, he received a commission in the First Royals, or Royal Scots. He was present with a detachment at the repulse of the British forces at Bergen-op-Zoom, on the 14th of March in that year, and whilst holding a flag of truce on the ramparts, the top of the staff was shot away by a musket-ball. In the summer of the same year he was ordered to Canada, and was in the transport-ship "Leopard" when she was wrecked on the island of Anticosti, at the mouth of the St. Lawrence.

Young Vignoles did not return to England till after the battle of Waterloo, when he obtained his lieutenancy, and was ordered to Fort William, in Inverness-shire, at the foot of Ben Nevis. During his furlough at Christmas time, he made the acquaintance of Professor Stuart, the celebrated philosopher, and through him obtained an introduction to General Sir Thomas Brisbane, who, a few months later, appointed him an extra aide-de-camp, and he joined the General at Valenciennes in May, 1816. He seems now to have been put on half-pay, but did not actually sever his connection with the army till 1833.

Mr. Vignoles married in 1817, and immediately afterwards sailed for South Carolina, with a view to recover a large estate which had been granted to the family by the British Government. He found that the Americans had confiscated tho property, and was therefore unable to reclaim it. He, however, soon obtained employment, and for the next few years was engaged on a survey of South Carolina and the adjoining States. In 1822, just before he returned to England, he published in America a full account of the Dominion of Florida, accompanied by a highly-finished map, which remains to this day the best, and, indeed, the only trustworthy, map of that little-known country.[1]

On reaching Europe he was almost immediately engaged by the Messrs. Rennie on the projected railway to Brighton and on other works; and shortly afterwards undertook surveys in connection with the proposed Liverpool and Manchester railway. He even began, in a measure, an independent career, part of which he has sketched out in his comprehensive and interesting address on

[1] *Vide* "Observations on the Floridas." 8vo. New York, 1823.

assuming the chair as President of the Institution, on the 6th of January, 1870.[1]

In 1830 Mr. Vignoles, in conjunction with Captain John Ericsson, devised a new method of ascending steep inclines on railways by introducing, in the centre of the road, a third rail, which was nipped by two horizontal rollers actuated by a lever from the locomotive. This centre-rail system was the same in all essentials as that afterwards employed in the zigzag line over the Mont Cenis Pass; but the system was not practically worked, doubtless owing to the fact that improvements in mechanical construction were proceeding rapidly, and more than enabled the ordinary locomotive to cope with any incline then deemed advisable.

After being occupied on the Oxford canal, and on a branch railway to Wigan, and from Wigan to Preston, afterwards called the North Union railway, and also executing some Government surveys in the Isle of Man, Mr. Vignoles was engaged as Engineer-in-Chief of the Dublin and Kingstown railway, the first of the Irish lines, which was opened in December 1834. His position was now established as one of the leading civil engineers, and the works he carried out are too numerous to be minutely detailed in this notice; but mention should be made of, amongst others, the Sheffield and Manchester railway, with the longest tunnel then projected in England, and at the time thought to be almost impossible of execution. About this time Mr. Vignoles was consulted concerning the execution of many of the earliest Continental lines, of which it may suffice to name the Paris and Versailles, the German Union railway, lines in the then Duchy of Brunswick, Berlin, Hamburg, and the Hanoverian lines.

Contemporaneously with these undertakings he occupied himself in studying the possible improvement of the railway bar then mostly in use, and introduced the flat-footed—now generally known as the 'Vignoles'—rail, which has, on the Continent, nearly superseded every other form.

In 1841 Mr. Vignoles was elected to the first Professorship of Civil Engineering established in England, and gave his opening lecture at University College on the 10th of November. He was also pressed by the Government of the day to plan the system of railways for India; but the negotiations fell through owing to Mr. Vignoles requiring very heavy insurances on his life. In 1844 he was specially invited to Germany by H.M. the King of Würtemberg, and he spent a few months at Stuttgart in consultation

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxix., p. 272.

with the King and his advisers as to the projected railways of that State. On the completion of his mission he was presented by His Majesty with a gold snuff-box set with diamonds, with a portrait of the King on the lid.

It was not long after this that the great railway mania set in throughout England, and Mr. Vignoles was professionally engaged on a vast number of lines; a few only, however, being completed, and those nearly in accordance with his original design. Amongst these may be mentioned the East Kent, now called the London, Chatham, and Dover, the Little North-Western, now incorporated with the Midland; and in Ireland, the Waterford and Limerick, and other central lines. From various causes the completion of these lines passed into other hands. Mr. Vignoles directed his attention abroad, and undertook works of great magnitude in Russia. In 1847 he visited St. Petersburg at the invitation of H.I.M. the Czar Nicholas, and from this date, during five or six years following, Mr. Vignoles paid many visits to Russia, where he had a large professional staff. His chief work in that country was the suspension bridge at Kieff, over the river Dneiper, the longest of its kind in the world. A beautiful model of this bridge, which was shown in the first International Exhibition of 1851, was unfortunately burnt in the fire which destroyed the tropical end of the Crystal Palace; but a duplicate of it had been presented to the Emperor of Russia, and is now at the Winter Palace in St. Petersburg.

In 1853–5 Mr. Vignoles began and carried out the first railways in Western Switzerland. He had, in 1854, made the first surveys of the Bahia and San Francisco railway in Brazil, but the works were not commenced till the year 1857, and were completed in 1861, Mr. Vignoles being the Engineer-in-Chief. In the winter of 1857–8 he was invited to undertake the line of Spanish railway already alluded to. The late Mr. Brassey was the contractor, and the works were carried out with the fidelity and thoroughness characteristic of all engagements undertaken by that gentleman. The line passes through a mountainous and beautiful country, which has since attained notoriety as one of the principal strongholds of the Carlists. The effect of the desultory civil war lately raging in the Basque Provinces has unfortunately been greatly to injure, if not to destroy, large portions of the works on this railway.

The last important undertaking on which he was engaged was the line from Warsaw to Terespol, in carrying out which he was again able to rely upon the co-operation of his old friend,

Mr. Brassey, as contractor. Mr. Vignoles had for some years retired from the active duties of his profession, but was consulted by many of his brother engineers on important schemes brought forward from time to time.

He took great interest in scientific matters generally. He was elected a Fellow of the Royal Society in 1855, and was also connected with the Royal Irish Academy, the Royal Institution, the British Association, the Royal Astronomical and several other societies. He also received decorations from the Emperor of Russia, the late Queen of Spain, and the present Emperor of Brazil; and was a J.P. for the county of Hants. When superintending the works of the Tudela and Bilbao railway in Spain, he hospitably entertained the members of the astronomical expedition sent out by Government in connection with the total solar eclipse in June 1860, providing also a map of the shadow path thrown by the eclipse. Ten years later he accompanied the Government expedition that sailed in the "Psyche" for the purpose of observing the eclipse of December 1870. In this case his ardour must have been somewhat abated by the wreck of the vessel, but his wonderful energy and vitality enabled him to endure with equanimity hardships and discomforts which would undoubtedly have been attended with grave consequences to any ordinary man of his age.

Mr. Vignoles was one of the fathers of the Institution, having been made a Member on the 10th of April, 1827. In October 1869, the standing order relative to the nomination for the Presidential office was suspended, in order that Mr. Vignoles might be chosen. At the general meeting in December he was duly elected President; and in that capacity presided over the debates of the Institution with a vivacity and intelligence characteristic of his temperament, but really extraordinary in a man of his advanced years. Those mental and bodily faculties he retained unimpaired to the last. Although somewhat imperious, he was of a most kindly disposition, and was a warm-hearted friend. Rather under the middle height, and of well-proportioned, compact build, his energy and capacity for work were remarkable; and in his demeanour and general bearing he was a thorough gentleman of the old school. Mr. Vignoles' death ensued after a short and painless illness, at his marine residence near Southampton, on the 17th of November, 1875, in the eighty-third year of his age. The obituary notices which appeared in the papers at the time were all characterised by a warm appreciation of the services he had rendered, and testified to the respect in which he was held, both by his professional brethren and by the public at large.

Captain WILLIAM INNES, R.E., was the eldest son of Colonel Thomas Innes, commanding the Royal Aberdeenshire Highlanders Militia, of Learney, Aberdeenshire, and was born in the year 1841. In 1853 he was placed at the Ordnance School of Carshalton, at that time the Government preparatory school for Woolwich; and in 1855, the entrance to the Ordnance Services, by nomination, being then abolished, he passed into the Royal Military Academy by the first competitive examination. After a three years' course of study, he left the Academy with distinction as First Cadet of the year, and elected to take his commission in the Royal Engineers, obtaining his lieutenancy on the 22nd of June, 1858. From a very early period of life he had shown great aptitude for science, and his character and attainments at the Military Academy led to his being selected, early in 1859, for employment on the works in progress on the fortifications of Dover, for which he designed Fort Burgoyne, under the direction of Colonel Du Cane. He continued there till January 1862, when the alarm of war with the United States on account of the "Trent" affair occasioned the despatch of troops to Canada. The navigation of the St. Lawrence being closed at that season, the route *viâ* St. John's, New Brunswick, had to be adopted, and Lieutenant Innes, being attached to the 4th Company, Royal Engineers, which formed part of the force sent out, on reaching St. John's, was immediately employed in the military survey of the United States frontier, and of the line of communication between St. John's and Lower Canada.

On the settlement of the dispute with the United States, Lieutenant Innes was sent to Halifax, and for five years was occupied in the construction of works for the defence of that harbour at Point Pleasant and George's Island, the fortifications of which he designed, with a prevision as to the future requirements of coast defence very much in advance of the time. During the winter months, when the rigour of the climate necessitated the suspension of the works, he obtained leave of absence, and repeatedly made journeys through the United States and Canada. Being ever on the outlook for opportunities of acquiring professional information from active service, and anxious to observe the operations of the war at that time raging in the United States, he applied to the authorities at Washington for permission to visit the northern army. Meeting with a refusal, and resolved not to be baulked, he cautiously approached the lines of the contending armies, and watched for an opportunity of passing the outposts. At length, favoured by a dark night, by the aid of a guide, he ran through

the pickets and patrols near Harper's Ferry, and succeeded, with much risk of life and at great pecuniary cost, in reaching Richmond. He had provided himself with introductions to officers of rank in the Confederate forces, and was well received in Virginia, enjoying opportunities of seeing their army in the field, visiting Charleston and Fort Sumter, and studying whatever interested him in a professional point of view. His return to the northern side was again attended with considerable hardship, having to cross the Potomac, and make his way on foot to Baltimore through the patrols of the northern army, when he narrowly escaped arrest as a spy. During the Fenian raids in 1866 he accompanied the field force sent from Halifax to observe the New Brunswick frontier. At Halifax he was distinguished as a regimental officer, and as a most able engineer. While here he carried out a series of experiments upon the proper method of ventilating powder-magazines, or other subterranean buildings; and these experiments resulted in a complete revision of the old Ordnance regulations for the proper execution of a duty most important and interesting to all engineers. He returned to England in 1867, and, after a short stay at the Isle of Grain, was employed on the Spithead forts at Portsmouth, then just above high-water mark; from thence, in May 1868, he went to Portland, where he was employed in the construction of a similar work at the head of the breakwater. When, in 1869, his distinguished relative, Colonel Sir J. W. Gordon, K.C.B., R.E., was appointed Inspector-General of Fortifications, he chose Lieutenant Innes as his A.D.C., and was accompanied by him in his inspections of the fortifications throughout Great Britain. He had thus, from his passing the threshold of the profession, on quitting the Royal Military Academy, been for ten years continuously occupied in the highest department of his branch of the service; and when his appointment as A.D.C. to the Inspector-General of Fortifications was sadly terminated by Sir W. Gordon's death, his eager temperament led him to look for larger and more comprehensive work than could then be found for him at home. For some time he filled the appointment of District Engineer Officer at Shoeburyness, where his work was mainly connected with the interesting artillery experiments then in progress, and, as was his invariable habit, interested himself keenly and worked with all his might at whatever he had in hand.

Having in 1871 attained the rank of Captain, he eventually, in 1872, accepted the appointment of Assistant Colonial Engineer of the Straits Settlements, and was given charge of the Penang district. Here his employment was almost entirely of a civil nature,

although he still kept up his interest in matters connected with his military profession.

The difficulty of carrying out the works necessary for a young and wealthy colonial settlement was enhanced by the utter want of an efficient staff. The population of Penang is well described in a letter from Captain Innes written in 1873, in which he says: "We have the most extraordinary jumble of nationalities here you ever saw; there is pretty well every sort of European amongst the small number of whites, to begin with. The great bulk of the natives are either Malays, who are the real natives, Tamils, or Chinese—a large proportion of these two last being birds of passage only; but there are sprinklings of Jews, Arabs, Abyssinians, and nameless heathen of all sorts from the Red Sea; every kind of Indian, Burmese, and Siamese from the north; and Javanese and outlandish Malay tribes *ad libitum* from the Archipelago generally." From these Captain Innes had to make his own staff; and although he complained of the great difficulty, he seems to have succeeded in the task, in some cases taking Malay and Chinese boys from school to train them himself in his office. The principal works carried out by him while at Penang were, a new prison, at a cost of £20,000, and a bridge over a tidal river 600 feet wide and 15 feet deep at low water; he had designed a town-hall, and was engaged in designing two lighthouses at the time of his death. Besides this work, he had, of course, the carrying out of the roads, drainage, and other engineering works of the settlement. In the course of his duties as Colonial Engineer he had carried out surveys of the settlement, and was fully acquainted with the newly-acquired territory of Perak. As at present much interest is concentrated on this part of the world, some description of the country from the pen of Captain Innes will be interesting. In 1873 he wrote from Penang: "The country is extremely beautiful both here and at Singapore; the Malay peninsula is a rugged, hilly country all the way up the middle, but with low, flat plains chiefly skirting the coast; and where you get one of our settlements, cultivated like a garden, in the low country, with a background of steep hills clothed with dense forest to the top, and occasional bare peaks, the effect is very fine indeed. There are no seasons worth mentioning in the Straits; the weather is always showery, the whole landscape always fresh and green, and the thermometer never below 70°—seldom so low. It is not bracing, and one cannot work without perspiring at every pore." In July 1875 he wrote: "I've done a good deal of exploring into the new territories we have got lately, which I find very enjoyable, and, con-

trary to the preconceived notions of tropical jungle, not unhealthy. There are very few inhabitants indeed outside our old settlements, which are densely populated; $\frac{99}{100}$ths of the country is covered with a dense and lofty forest; there are no roads, and scarcely any footpaths; the natives always stick to the streams, and travel by water, and it is precious hard work when you do not follow their example. I once took a long day and a half in going 12 miles from one river to another."

A few weeks before Mr. Birch's assassination Sir W. Jervois made an official tour, as governor, through the district of Perak, in which Captain Innes attended him. One object of the journey was to assemble the native chiefs, and to attempt to reconcile them to the necessary conditions of a settled government; but they kept aloof, and manifested a suspicious and unfriendly disposition, and Captain Innes, in his last letter, seemed to entertain a presentiment that all was not right.

When the news of Mr. Birch's assassination, on the 2nd of November, arrived at Penang, Colonel Anson, the Lieutenant-Governor, at once ordered Captain Innes to Perak, to temporarily replace him. He arrived, with some small detachments of troops, at the Residency on the 5th, and on Sunday, the 7th, marched out to attack two stockades which the Malays had formed up the river, and from which it was feared they would concentrate a force to attack the Residency. Unfortunately, it appears that for the only gun available no boat, from which to fire it with safety to its stability, could be found; the expedition consequently started with no artillery but a few rockets. After a march of about 1 mile, fire was suddenly opened from a stockade concealed by tall maize and plantain-trees. The rockets were brought up, but proved useless. A retreat being out of the question under the circumstances, an attack was made by the troops in open order, in carrying out which Captain Innes, while accompanying the officer in command of the troops, was shot through the heart, and fell dead without uttering a sound.

Captain Innes has been blamed for the failure of this attack, which was undertaken by his order while acting as Resident at Perak in the place of Mr. Birch. It is easy to be wise after the event. It appears that every officer with him agreed as to the necessity for the attack and its mode of execution. So serious a resistance was evidently not anticipated; and had not the rockets proved useless when tried, it is probable that they would have cleared the stockade of its defenders, as was done under similar circumstances a few days afterwards.

The "Papers on Subjects connected with the Duties of the Corps of Royal Engineers" have been enriched by several communications from Captain Innes of interest to engineers generally. These include "Notes on the Exterior Slopes of Fortifications at Dover;"[1] "Notes on the Defences of Charleston, South Carolina;"[2] "On Damp in Powder Magazines as affected by Ventilation;"[3] and "Notes on Supply, Storage, and Testing of Portland Cement;"[4] and in 1871 he joined in a discussion at the Institution on the Strength of Cement.[5] In 1874, a somewhat one-sided advocacy of casemated as opposed to open batteries for coast defences having appeared in the "Royal Engineer Journal," he wrote two letters to that paper, in which he ably upheld the superior advantages of well-laid-out earthen batteries in positions suitable for their use, at the same time combating the idea of the alleged practical invulnerability of the present type of casemated batteries. He also sent home from Singapore, for publication in the "Royal Engineer Journal," an interesting series of papers on Coast Defences.

During his training at the Royal Engineer establishment at Chatham, and indeed throughout the whole of his service, Captain Innes was remarkable for an assiduity and conscientious attention to his duties, which, added to his natural talents, marked him out, in the opinion of his brother officers, as destined to the highest distinction in the corps. Indeed, his immediate contemporaries regarded him as one of the most promising officers among the Captains of Royal Engineers. The thoroughness of his investigations into any subject under consideration, his experience, the logical precision of his reasoning, and the modesty of his language, attached the greatest weight to any opinions he might give on professional questions, such as were frequently discussed at the War Office among the officers of the Royal Engineers. In all the posts which he held he retained the reputation for excessive devotion to duty, and of intelligence combined with extraordinary clearness of decision and purpose. Of a shy, retiring manner, with the utmost zeal and ardour in his work as a soldier and as an engineer, with perfect self-suppression in the execution of all work intrusted to him, having naturally a gentle and amiable disposition, but the greatest fearlessness in the performance of his duty, even when against the interests of his immediate associates, Captain Innes always upheld nobly the character of a conscientious "officer and gentleman."

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[1] New Series, vol. x., p. 128. [2] New Series, vol. xiii., p. 16.
[3] " vol. xvi., p. 69. [4] " vol. xxi., p. 1.
[5] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxii., p. 319.

During his Staff employment in London he was elected an Associate of the Institution, on the 7th of December, 1869; and there was no more regular attendant in the library or theatre of the Institution of Civil Engineers than Captain Innes; and nothing there pleased him more than the well-known speech of his chief, Sir William Gordon,[1] in reply to the complimentary remarks by the President, Mr. Vignoles, upon the military engineers of this country. In the death of Captain Innes the Civil Engineers of Great Britain have lost a most ardent friend and a most promising Associate; the Royal Engineers must lament the loss of a brave and accomplished comrade; the country is deprived of the services of a scientific soldier who devoted his whole life to her interests, and died gallantly in action, to her honour.

MR. FREDERICK PECK was the seventh son of the late Mr. William Peck, of Cambridge, who for many years carried on an extensive business as a builder in that town, and was born on the 26th of April, 1828. He learned the practical part of the profession of an architect in his father's works, and was subsequently articled to Mr. Giles, an architect, at Taunton. For a time he was in practice as an architect at Maidstone, but for the greater part of his professional career he resided in London.

Among the public works erected by him, mostly taken in competition, were the Agricultural Hall at Islington, the new Town Hall at Cambridge, the Cemetery at Bury St. Edmunds, the Albert Memorial College at Framlingham; also the Trent and the Bedford Colleges, Lincoln Gaol, Whittlesea Workhouse, Maldon Workhouse, Beddington Orphanage, the School House and Works Hall at Leiston, besides several churches and private residences. His was also the accepted design for the intended International Exhibition building at Madrid, which, however, has not yet been erected.

Mr. Peck was a man of great energy and resource. He had unusual capacity for work, and had attained a considerable degree of eminence in his profession; but in the early part of 1874 an overworked brain obliged him to seek perfect relaxation for a time, and, with this view, he retired to Yoxford, in Cambridgeshire, where he died very suddenly on the 23rd of March, 1875.

Mr. Peck was elected an Associate of the Institution on the 11th of May, 1869.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxix., p. 319.

MR. WILLIAM RAWLINSON was the son of Robert Rawlinson, a farmer, of Guile House, Melling, Lancashire. Having early shown a turn for mechanics, he was apprenticed to Messrs. Joseph Betteley and Co. (now Wainwright and Co.), engineers and ironfounders in Liverpool. After passing through the usual apprenticeship, and being subsequently employed by them, he went to Pernambuco, in the year 1858, to manage the establishment of Messrs. C. Starr and Co., at that time the principal engineering workshop in the place. He remained with them till 1863, when he became Assistant Engineer on the Recife Bridge, a work which was completed and opened in 1865.

Mr. Rawlinson then went to the adjoining province of Parahiba, and assisted in erecting two iron bridges for the Government. In 1867 he obtained the position of manager to a small local railway which had been constructed by Mr. W. Martineau, M. Inst. C.E., and this position he retained till 1872. After a visit to England, he returned to Pernambuco, in December 1873, to take charge of the works of the Boa Vista Bridge for Messrs. Watson and Smith, the contractors, and it was while in charge of this work that he died, on the 21st of October, 1874.

Mr. Rawlinson was elected an Associate of the Institution of Civil Engineers on the 11th of January, 1870.

MR. FREDERICK WILLIAM TAYLOR[1] was born in London in 1807, and in early life was employed as foreman in Messrs. Maudslay's well-known factory. About this time the Ottoman Government sent a request to the English Government to be supplied with an engineer capable of directing the construction of the new buildings and shops of the Marine Arsenal, and Mr. Taylor was chosen for the post. He arrived in Constantinople in the year 1833, and speedily carried out the work with success. Having finally established himself in Turkey, he married, and became the head of a family, the members of which occupy an honourable position in Pera. Mr. Taylor was next employed in constructing several factories and other buildings, notably the cannon foundry for the arsenal at Tophaneh, by which his reputation was fully established in the eyes of the Turkish Government. He was subsequently engaged in building the forges and rolling-mills at Hasskeui; the Imperial Mint, which he also provided with the necessary machinery; additional workshops at Tophaneh, and many

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[1] Compiled principally from the "Levant Herald."

other important works. During the Crimean war Mr. Taylor was employed by Admiral Grey in the construction of a dock at Yali Kiosk for repairing the English men-of-war, which he completed in less than a year. One of his last works was the construction of the rolling-mills for the plates of ironclads at Hasskeui. These have been worked most successfully for several years past. As a reward for his services, Mr. Taylor was appointed Engineer-in-Chief to the Evcaff, in order to superintend the repairs of the mosques and the waterworks, which are under the control of that ministry. He also built the Government steam-printing factory, and rebuilt the Imperial Fez Factory, after its destruction by fire. Mr. Taylor filled several important missions. In 1869 he was appointed by the Council of Ministers a member of the Military Commission which was sent to Belgium and England to study the latest improvements in arms and war material. On his return from England he was also appointed to superintend the reconstruction of the army flour-mills at Oun Capan; but the fatigues of the journey and the severity of the English winter, to which he was no longer accustomed, had produced a visible effect on him, and he had barely finished this important work when he was attacked with the illness of which he died.

Mr. Taylor was universally esteemed for his probity and uprightness, as well as for his amiable character. He was elected an Associate of the Institution of Civil Engineers on the 9th of March, 1841, and died on the 20th of June, 1875.

SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Levelling with Aneroid Barometers, executed on Five Sections of the Reduced Scale Staff Map of the Kingdom of Saxony.

By DR. PAUL SCHREIBER.

(Civilingenieur, xxi., 4, 5 and 6, 1875, cols. 273–294, 381–405, 2 pls.)

The levelling treated of in this essay was carried out in the years 1870–72, partly by the Author alone, and partly with the assistance of Herr G. Helm, Head Master of the Dresden School of Art. Among the five sections taken, that of Grossenhayn was worked on an essentially new method perfected by himself and Herr Helm, and which the Author greatly recommends after trial, the temperature of the air being determined by a new arrangement of Professor Bruhns, Director of the Leipsic Observatory. The readings were made with two aneroids of different construction, always carried in the same positions, and protected as much as possible from changes of temperature in a box, ten minutes at the most being required for the determination of the altitudes.

THE FIELD WORK.

In Saxony the levelling was so advanced that it was simply necessary at the commencement of the measurements to take the pressure of the air at the bench-mark, and to compare it with the pressures at the stations to be determined, after which it only remained to correct the readings at each station by the changes observed in the pressure during the day at any one station.

As long as the work proceeded in the neighbourhood of Leipsic (at stations Markranstädt, Leipsic, Oschatz, and Pegau) the standard barometer of the Leipsic Observatory served for the reduction of the observations, but on the Grossenhayn section the *pressure curve* was obtained from the joint work of two observers, each furnished with a French line and a millimètre aneroid.

1. As there are always two observers, working distinct districts, which only meet in certain "chief centres," the maximum amount of working power is obtained.

2. The 'pressure curve' is found by the regulated arrivals of the observers at the chief centres.

3. Every two chief centres should only be one hour's walking distance apart.

The first principle must be strictly observed when the quickest possible exploration of a district is required, and where the points lie near each other. But in the exploration under notice, the stations were often one hour's walking distance apart, so that if the work was to proceed with any rapidity, a good deal of physical exertion on the observers' part would have been indispensable. This principle was accordingly modified, and observers I and II were each day interchanged, the former being directed to visit every point, while II had only to observe at the chief centres, and at such points as he must pass in going from one chief station to another.

By the aid of a map on which the work of the two observers is indicated by distinguishing marks and letters, and by extracts from their day-books, the Author proceeds to illustrate how the work was carried out. The starting point was the bench-mark at the railway station of Riesa, the closing point that on the Guildhall at Grossenhayn, a district of 8·35 square miles, and each observer noted in his day-book the astronomical time of his observation (in hours and tenths) at each station, as well as the readings of his two aneroids, side by side. The method of working is the following:—

The four aneroids having been compared, observer I sets out from Station A at 19 hours, and arranges to arrive at the second chief Station B at exactly 20 hours, determining on the way any minor stations that may be necessary. II meanwhile waits at A, reads the pressure at 19·5 hours, and again exactly at 20 hours, and then proceeds as quickly as he can to B. The pressure curve is thus determined half-hourly from 19 to 20 hours. II must not leave Station A until I has read the pressure in B; he ought rather to delay somewhat his last reading in A. At B observer I leaves a notice giving the time he will arrive at the next chief Station C, and stating what points he will visit *en route*. II has therefore only to see that he does not leave B until I has arrived at C, in order to cause no break in the determination of the pressure curve from the time of his own arrival in B. The work is then carried on as before. The observers should meet at least once during the day, preferably at mid-day, in order to compare the instruments, and to discover any changes in either of them.

The Author then recounts various precautions that must be taken to prevent failure in the work, instancing two slight mishaps which occurred in the one under notice; he also indicates how any delay on the part of observer I in arriving at his chief station may be repaired. After giving further directions how the work should be carried on with the greatest accuracy, he sums up the advantages of his method to be—

1st. That it allows of the maximum amount of working power, and the greatest speed in execution.

2nd. That it insures the greatest accuracy, because the pressure

changes are always noted in the immediate neighbourhood of the district to be explored, and the instruments can often be compared with each other.

The Computation of the Readings.

(*a*) Reduction to a constant temperature and to the mean values.

Of the three corrections applied to aneroid readings, only one, that for temperature, is applied after the known manner.

As only differences of pressure are taken into account, a reduction of the aneroid readings to the absolute barometrical ones would be of no account, but it was highly necessary to compare all the readings of the four aneroids with the constant variation of the quicksilver barometer, in order to see that the *aneroid readings reduced for temperature are the same for the same pressure, when the instruments also agree with one another.*

For this purpose the comparison observations of the four aneroids are collected in a special book, with notes as to when and where they were taken. These observations and remarks are written on the left side of the book, the reductions on the right. The Author gives an extract from his comparison book for the day already chosen as an example (29th–30th August). In this book the readings of the line and millimètre aneroids are reduced to a constant temperature respectively, and all are brought into a common term in order to find the means, when the deviation of each instrument from these mean values can be found, and the work checked.

After these reductions in the comparison book are completed the computation of the heights is commenced. They are made for each instrument singly, so that the agreements of the heights from the readings of the line and millimètre instruments of the same observer furnish a check both on the observations and the computations. Tables 4 and 5—one for the readings of each observer separately—are given as examples, and from them it may be seen that the more accurately the aneroids have been adjusted the less will the corrected means of the observations differ from the readings of the standard barometer. *The means of the observations now serve for the construction of the air-pressure curve.*

(*b*) Construction of the air-pressure curve.

To this end the readings of the same observer, or those of both observers at the same station at different times, are brought together, and worked out as shown by the Author in a table, from which the means of the pressure changes, as measured by the line and millimètre instruments respectively, are arrived at, furnishing thereby the data for the construction of the curve.

In a pressure curve drawn by the Author the times of observation are shown as abscissæ (1 hour = 2 centimètres), while the pressure changes form the ordinates in such proportion that 1‴ (1 French line) pressure change is represented by a line of

100 millimètres, also 0·01 (French line) by 1 millimètre. He then goes into the construction very fully, showing how to deal with any difficulties that may have arisen in observation. The end of the curve shows the amount of the pressure change from the commencement of the measurements to the last comparison at night, the curve itself representing the changes at Station A during the day. But as each ordinate, that served for the drawing of the curve, may have some error, and as these errors may accumulate, the end of the curve will generally have a very wrong position at the first attempt to draw it.

The 'normal point,' which ought to coincide with the termination of the curve, if the latter be right, is next calculated as follows:—

The means of the simultaneous readings of all the instruments at the first and last station give the following values:—

		Mètres.		Millimètres.		Hours.		
Station A.	Height	105·0;	Pressure	756·39;	Time	19·0;	August	29th
" H.	"	123·4;	"	751·93;	"	8·0;	"	30th

$$\Delta h = +18 \cdot 4, \ \Delta b = -4 \cdot 46.$$

As H is higher than A by 18·4 mètres, the barometer reading must be lower in H than A by 1·6 millimètre; therefore if the pressure remained the same in A, the barometer would fall 1·6 millimètre by being removed to H; as, however, it has fallen by its removal from A to H 4·46 millimètres, the pressure has been diminished over the whole district as well as in A.

Millimètres.		Millimètre.		Millimètres.		French Line.
4·46	−	1·60	=	2·86	=	1·26.

This amount of 1·26 French line now gives the ordinate for the normal point to the abscissa 8 hours; as this point only differs from the terminal point of the curve by 0·01 French line, the curve may be considered correct. The agreement, however, is a matter of pure chance, and has not again occurred in the work. If, therefore, any discrepancy should occur, the whole curve must be corrected by assuming every ordinate as equally wrong, and distributing the error proportionally over each.

(*c*) Computation of the heights.

In this computation the tables already commenced are proceeded with, the readings of one day being reduced to those which would have resulted if they had all been taken at one instant, namely, at the time of the first comparison in Station A. These corrections are worked out in both lines and millimètres, and by applying them to the reduced mean barometrical readings, the actual barometer readings are obtained, which must now be considered entirely as functions of the differences in height of the stations. If now the barometer reading (*b*) at A be subtracted from that at each of the other stations, the difference of pressure at the stations with A is arrived at, which is positive or negat[illegible]

according as A is higher or lower than the places concerned. The $\Delta' b$ thus obtained are now computed into $\Delta' h$ by the formula $\Delta h = - 11 \cdot 1$ mètres Δb; and so the heights of the stations with regard to A are determined.

These results should be the same from both instruments, but at all events the mean values of Δh must be taken, and added to or subtracted from the height above the sea of Station A, in order to fix that of all the other stations; and as there have been at least four separate determinations for the chief stations (both observers having determined them), the chances of error in their case are greatly diminished. In the example given the approximations are wonderfully close throughout.

All changes of millimètres into lines, &c., or of Δb into Δh, and so forth, are of course made by tables.

In the case of the standard barometer and one observer with two aneroids, the computations are identical with those already described, save that the aneroid readings do not require reduction to their mean values.

The Results.

These are investigated by the undermentioned tests, viz.:—

I. *Comparison of simultaneous aneroid readings.*

This is done by inquiring (*a*) into the comparison of two aneroids, and (*b*) into that of four, as used on the Grossenhayn section.

(*a*). Comparison of two aneroids.

In this test six, of which five[1] were large "Naudet," aneroids were used, the sixth being a "Goldschmid's" instrument. With these 2,391 simultaneous readings were taken, and invariably with two aneroids differently graduated, the observations varying from 813 to 147 in number in each case.

To compare the results all the line readings were changed to millimètres, and their differences found, then the mean of the daily differences was computed, as also the disagreement of the differences from the daily means. Next these disagreements were arranged according to their magnitude, it being noted how many occurred between the limits

Millimètre.	Millimètre.
0·0	± 0·1
± 0·1	± 0·2 &c.

and the percentage of these numbers then taken.

If now the magnitudes of the deviations be considered as abscissæ and the percentage numbers as ordinates, a curve will be obtained which gives an idea of the agreement of the two instruments, and assuming both as equally good, the greatest deviation

[1] Three graduated to millimètres and two to French lines.

of one aneroid from the reading it should have given on account of the pressure can be determined. As the maximum deviation *of the Naudet aneroids amounted* (by these experiments) *to* 0·55 *millimètre, the greatest error introduced by the reading of one Naudet aneroid* = ± 0·27 *millimètre.*

An error of $\frac{1}{10}$ millimètre in the barometer corresponds to about 1 mètre in height, therefore the altitudes found will at the most differ ± 3 mètres from their true values, supposing that these errors alone influence the results.

(*b*). Comparison of four aneroids.

The foregoing results are remarkably confirmed.

Ninety-five comparisons of the four aneroids were made during the work under notice, without showing any remarkable change in the readings of any one instrument, between the 30th of August and the 19th of September, and the results prove that the maximum error in any one aneroid reading lies between 0·3 millimètre and 0·4 millimètre, that this only amounted to 1 per cent. in the worst instrument (No. 5), and that the greatest deviation (as in the comparison of two aneroids) of one aneroid reading from that fixed by the pressure amounted to ± 0·27 millimètre, which gives an error (as before) of ± 3 mètres in the altitude so found. It is deduced therefrom that the probable error in a height, found by the reading of one aneroid, supposing no other sources of error exist, only amounts to ± 0·8 mètre. This deduction is pretty near the mark, as repeated measurements of the same stations with aneroids gave a mean error of ± 0·84 mètre.

II. *The pressure curves.*

In order to show the accuracy of the pressure curves obtained from single observations, and the consequent utility of his method, the Author constructed fifteen curves, and examined the differences (if any) between their terminal and normal points. The result is that the mean error of each ordinate, out of which the whole curve is constructed, is only about 0·0092 French line, and that the maximum error is only 0·020 line, supposing that each ordinate of this curve is equally wrong.

III. *Comparison of the heights found by the aneroids with those obtained by spirit-levelling, and with those inserted on the General Staff map.*

In the published accounts of the spirit-levelling in Saxony, forty-one altitudes occur which were measured with the aneroids, but not used as fixed points in the computations. Of these 26·8 per cent. agree with the Author's results, while the remainder show + and − disagreements in equal proportions, so that the sum of the positive errors amounted to + 46 mètres, that of the negative to − 40 metrès, excluding the existence of any constant error; consequently the mean error in an altitude found by two aneroids = ± 2·1 mètres.

The average difference for altitudes on the Staff map and those

found by the aneroids = ± 5·1 mètres out of a total of 159 identical heights measured; but this result, though unfavourable, loses its significance when the altitudes on this map, found by vertical angles from trigonometrical stations, are compared with those determined by spirit-levelling, where out of a total of thirty-four identical heights an average difference of ± 6·5 mètres occurs. This is probably due to stations being considered the same which really are not so, since no attempt is made to fix exactly the sites of the altitudes on the map. If, therefore, the greatest differences be omitted as due to these causes, the probable error in an altitude measured by two aneroids is about ± 2 mètres.

IV. *Comparison with Bauernfeind's and Schoder's results.*

Bauernfeind's and Schoder's experiments strongly confirm these results where, on railroads with the rails as fixed points, no differences in the setting up of the instruments is possible. Bauernfeind's results show a probable error of ± 1·09 mètre out of eighty-two observations of altitudes, whose greatest differences in height varied from 166 mètres to 51 mètres, while Schoder's show a probable error of ± 0·87 mètre out of forty-seven observations; and as both have taken the temperature into account, and have up to a certain limit used the strictest formula (Schoder his own tables), whilst the Author has entirely neglected the temperature, and computed by the formula

$$\Delta h = -11\cdot 1 \text{ mètres} \times \Delta b \text{ millimètres},$$

it follows that such omission and consequent simplification in the calculations is practically justifiable.

A calculation then follows to show that this method would save one-third in time over the older one, although the employment of two people instead of one must be set against such saving, whilst the cost of four aneroids is unquestionably less than that of one standard barometer and two aneroids.

E. H. C.

Graphical Statics. By Antonio Favaro.

(Atti del Instituto Veneto di Scienze, lettere ed arti, Series IV., vol. ii., 141 pp.)

The Author shows in this Paper how the modern science of mathematics is founded upon ancient science. Analysis and geometry have always struggled for the precedence, and although the invention of Descartes, of representing lines and curves by algebraical equations, favoured analysis, it is now admitted that geometry gives greater facility for representing problems and their results, in consequence of which it is now used in questions formerly entirely referred to analysis.

The step from applied science to practical application was made

by Culmann, who based graphical statics on pure geometry, and showed what part it was to play in the science of engineering; and the Author, following that system, divides his subject into— 1. Geometry of position. 2. Graphical calculus. 3. Graphical statics.

Geometry of position or projective geometry comprises principally the propositions of mathematicians, such as Euclid, Apollonius, Pappus, Desargues, Pascal, &c., remarkable for great penetration and ideas, but who are wanting in the scientific invention of the present day. Modern geometry employs both the synthetic and analytic methods without their disadvantages. The first advance in geometrical science was made by Desargues and Pascal in the sixteenth century; the analytical geometry of Descartes was followed by the differential and integral calculus and mechanics. At the beginning of this century Carnot proposed a new method of studying the geometry of the ancients, and published "Corrélation des Figures de Géométrie," "Géométrie de Position," and "Théorie des Transversales."

Poncelet followed with treatises on the projective property of figures and the theorem of reciprocal poles, which originated the schools of Steiner, Chasles and Staudt. About the same time Chasles in his works on ancient and modern geometry treated of the difference between pure and applied geometry. Steiner bases his system on the metrical and transformable property of figures; Chasles on the anharmonic ratio, homographic division and on involution, and does not make use of the law of continuity; whilst Staudt excludes the metrical property of figures, and treats geometry independently of measure, showing in its full force the law of duality and reciprocity by which all plane geometry is ruled.

The necessity of combining graphic operations with numerical calculations in designing has forced engineers to seek a uniform method, and as the numerical system has been found impracticable, it is now sought to apply the graphical method. Moebius having introduced it in his "Barycentrische Calcul," was followed by Gauss, Bellavitis and Grassmann, who explain the geometrical system of calculations. In France the remarkable work of Cousinery, "Calcul par le Trait," is supposed to have been the basis of Culmann's "Graphische Statik." In the graphical calculus all figures of whatever form are represented by lines, and through them addition, subtraction, division, raising to powers and taking out roots are carried out. The calculations of sections of earthworks for railways and roads are solved by the same method, and it is found to be more accurate than the approximate method of the mean of two extreme areas. It has been used on the Bavarian railways and more recently in Würtemberg, and it has also been applied by Muller and Rankine.

The graphical study of mathematics presents clearly to the eye mechanical problems which, by the analytical method, are difficult to grasp, and Poncelet has shown what use even the industrial

mechanic might make of such a study. Cousinery also uses this system in the solution of problems, in his "Calcul par le Trait."

Culmann defines it as the science which shows how the conditions of equilibrium of given forces, representable by means of algebraic expressions, can be found by constructive or graphical methods. With reference to the graphical calculus, he assumes for the statics the two following propositions relative to the composition of several forces applied to a point—the resultant of several forces applied to a point passes through that point, and the forces are composed by lines since they are capable of being thus represented. This being allowed, he shows the way in which all theoretical statics and the practical application of them are resolved in a uniform and simple way by two figures—the polygon of forces which gives the intensity of the resultant of the forces, and the funicular polygon which determines its position.

The Author then describes Cremona's application of graphical statics to reciprocal figures, and Culmann's exposition of the use of the graphical method in determining statical moments and moments of inertia. It is shown that though the funicular polygon is the simplest method of finding the resultant of a number of forces, the theory of the Giratory of Bellavitis, or of infinitely small forces placed at an infinite distance, as proposed by Culmann, offers the only means by which the composition of forces in space becomes possible.

The engineer, however, seldom has to treat forces in space, but generally those situated in a plane, and particularly parallel forces, for which he may adopt the usual method of the polygon of forces and the funicular polygon, by which the conditions of equilibrium of a frame or of a suspension bridge may be found. The graphical method shows clearly the relation between the moments of flexure and the breaking weight, it simplifies the long, troublesome and unreliable calculations for finding the most favourable position of a train of locomotives on bridges of various dimensions, and is of great help in solving problems relating to irregular figures which are so difficult to treat by the ordinary system. It also shows the ease with which moments of a superior degree of the same force may be obtained from simple statical moments of parallel forces in a plane, from which follows the known theorems relative to the ellipsoid of inertia and that of the central ellipsoid.

In treating of frames Culmann explains the equilibrium of external and internal forces applied to its transverse section, and applies it to the internal forces working in a rail, and their distribution in figures of the form of a crane; and he has also rendered great service to the engineer by graphically solving the strains on bridges, and more especially of continuous girders, in which the moments of inertia are continually varying; and lastly he treats of the equilibrium of retaining walls and stability of earthwork.

J. K. R.

Moment of Inertia of Plane Figures.

By PROFESSOR TH. REYE.

(Zeitschrift des Vereins Deutscher Ingenieure, July 1875, cols. 401–408.)

Every plane figure, with relation to its moment of inertia, can be represented by three points, in each of which one-third of the mass of the figure is concentrated. One of these points can be freely chosen upon a certain ellipse, whilst the other two are points of intersection between this ellipse and a straight line, the position of which depends upon the choice of the first point. It is therefore possible to represent the moment of inertia in an infinite number of different ways, the following being the most simple and instructive.

Let b be the base, h the height, m the mass of a triangle, and let one-third of the mass be concentrated in the centre of each of its sides: then the moment of inertia of those three points in reference to any axis is the same as that of the whole triangle. Calling r_1, r_2, r_3, the distances of the substituted points from the axis, the moment is

$$T = \frac{m}{3}(r_1^2 + r_2^2 + r_3^2).$$

For the base as an axis it is

$$T = \frac{m\,h^2}{6},$$

and if the density of the figure be $= 1$, viz., $m = \frac{b\,h}{2}$,

$$T = \frac{b\;h^3}{12}, \text{ the usual expression.}$$

In the same way, by regarding a parallelogram as composed of two congruent triangles, a system of five points may be substituted for it. Let, again, b be the base, h the height, and m the mass of the figure, then the mass $\frac{m}{3}$ will be concentrated in its centre of gravity, and in the centre of its sides the mass $\frac{m}{6}$. In relation to the base the moment then is $T = \frac{m\,h^2}{3}$, which expression, supposing density to be $= 1$, viz. $m = b\,h$, assumes the usual form of

$$T = \frac{b\,h^3}{3}.$$

A ring of r_1 inner radius, and r outer radius, can be represented

by four points of the mass $\frac{m}{4}$, placed in the angles of a square symmetrical to the centre of the circles. The length of the sides of that square is $\sqrt{r_1^2 + r^2}$, and the moment, in reference to a diameter, is

$$T = \frac{m}{4}(r_1^2 + r^2).$$

In case of a full circle ($r_1 = o$), and the density = 1, this expression assumes again the well-known form of

$$T = \frac{\pi r^4}{4}.$$

G. KA.

Riedinger's Powder-Ram. By H. KUHN.

(Deutsche Bauzeitung, Oct. 30, 1875, pp. 433, 434.)

Pile-driving by the explosion of gunpowder, as first introduced in America by Mr. Shaw, has lately become more general. Amongst those who have improved the original invention is Herr Riedinger, of Augsburg, who last summer advantageously employed a modified powder-ram in the construction of a third bridge over the Elbe at Dresden.

The object of using gunpowder for a motor is to substitute the elastic and strong pressure of explosive gases for the blow of the monkey, which causes in other pile-engines loss of mechanical labour. The explosion takes place in the mortar or gun, which is a cast-steel cylinder of 6 inches bore, 2 feet long, with a recess of about 2 inches, resting on the head of the pile. The ram, a cast-iron block of 13·7 cwt., is provided at its lower end with piston-rod and steel piston to fit the bore of the gun, whilst in the upper end is a similar bore, in order that if the ram happens to be thrown too violently upwards, a piston attached to the top of the frame enters the bore and thus, by compressing the air in it, checks the blow.

Both the mortar and the ram slide in guide-bars fixed to the frame, the latter being connected to the platform by means of hinges and a steadying bar, somewhat in the manner of a derrick. Opposite to the guide-bars, and parallel with them, is suspended on small bell-cranks an iron rail, which by a hand lever can be pressed against the ram. Thus it is possible to arrest or release the latter in every position.

The method of working is as follows:—After the pile and mortar are set, the monkey is hoisted up by a hand winch and arrested, a cartridge, containing from 8·5 to 11·2 drachms (15 to 20 grammes) of gunpowder, is thrown into the mortar and the monkey released.

The smaller cartridges were used if the ground was found to be very resistant, as too large a force is liable to split and jump the pile. In falling the steel piston enters the mortar, and by compression so heats the air in it that the cartridge explodes. The gases drive mortar and pile downwards, whilst the ram is thrown upwards and has to be arrested again by the break.

The principal features of the powder-ram are great efficiency, speed, and cheapness. Shunting the engine, setting the pile, and driving it to a depth of 6 or 8 feet, occupied from twenty-five to thirty minutes, so that with one engine twenty-four or even thirty piles can be driven during one day.

The best result obtained was thirty-four piles in twelve hours, each driven to a depth of 4 feet, at an expenditure of about 10·6 ounces (300 grammes) of gunpowder.

With regard to the velocity of blows, it was not found advantageous to fire more than twelve times a minute, as a quicker succession of blows not only makes it difficult for the men to do the work properly, but also causes mortar and piston to get too hot. If the fire be too quick it may also happen that the cartridge immediately after being thrown into the mortar ignites by the glowing remains from the former shot, and thus the charge is lost, and the monkey has to be hoisted up again by the hand winch.

The price of the pile-engine was £235; taking for amortisation and wear and tear 14*s.* 6*d.* per day, the expenses for one pile driven to a depth of 7·2 feet are:—

	s.	*d.*
For wages	1	11
For sixty cartridges	5	10
For the use of the engine	0	9
Total	8	6

G. Ka.

Foundations of the new Opera House at Paris. By M. Baude.

(Bulletin de la Société d'Encouragement, Sept. 1875, pp. 498–510, 3 pl.)

The site of the new Opera House at Paris occupies an area of nearly 2¾ acres. The ground underneath the stage is excavated to a depth sufficient to permit the stage to be lowered in its entirety, together with its decorations, some of which reach a height of 50 feet. In order to render this portion of the building fit for the reception of the machinery and other theatrical appliances requiring to be kept perfectly dry, a well has been excavated at a still lower level, with arches to support the superstructure. The total depth from the street level to the bottom of the concrete is, except immediately below the stage, 18 feet. In the latter case it is 36 feet, and extends over an area of 2,475 feet.

At first the excavation was carried on with facility, but as the depth increased, water was met with in large quantities, and the source traced to the hills of Belleville and Ménilmontant. To obviate this difficulty a large cofferdam was constructed, consisting of a double row of timber piles, with béton between them. The piles were nearly 12 inches square, 21 feet in length, and driven down by a steam pile-engine to a firm stratum. An iron pile was used to pierce the ground previously to the driving of the timber. The space between the piles was then dredged out, and it was originally intended to fill it with liquid béton composed of mortar and flint stones, in the proportion of 3 parts of the former to 4 of the latter. The mortar itself consisted of 40 parts of lime, 15 parts of cement, and 100 parts of sand. To keep the water down eight pumps were set to work, and it was soon found that there was no necessity for using liquid béton, but that it could be laid solid and dry, which the Author considers a preferable arrangement.

The trenches having been excavated, the béton was spread over the whole surface to a depth of 6·5 feet, and carefully levelled. It was then covered with a layer of cement 2 inches in thickness. Another layer of béton was superimposed, and upon it the inverted arches were constructed which formed the curved surface of the well. The arches were built in this manner to better resist the upward pressure of the water, which, however, did not average more than ½ ton per square foot of surface. The walls of the gallery, the pillars supporting the well, and the massive walls carrying the stage, were built simultaneously. The well is surrounded by a gallery varying in breadth from 6·5 feet to 13 feet. It is by means of the exterior walls of this gallery that the water is kept out of the well, which is perfectly staunch, and fulfils its object in rendering the space below the stage a completely watertight compartment.

The pressure upon the lower courses of the great wall supporting the stage, which has a thickness at the base of 8 feet, is nearly 9 tons to the square foot, which is about double the usual allowance. But this is surpassed by the weight upon the small columns of Jura marble, which support three times the former pressure—an amount which numerous experiments have shown to be quite consistent with safety. In the foundations of the building there are 124,262 cubic yards of masonry, costing all round close upon 5 guineas the cubic yard. The greater portion of the stone was delivered on the site, ready to be at once placed in position, thus enabling the work to proceed with regularity and despatch.

T. C.

Remedies against Landslips. By Luigi Torelli.

(Il Politecnico, September and October 1875, pp. 583–594.)

In 1874 a law was passed in Italy making the planting of trees compulsory on lands that come under the forest laws, which is found to be a great protection against landslips. The basin of the Po is especially mentioned as being capable of improvement by the planting of trees, and the districts of Varazze and Tirano are cited as examples of the benefits derived by so doing. The high price of wood had caused all the trees to be cut down even in the least accessible places, and letting the cleared land as pasture, at a very low rate, was mostly preferred to replanting trees that would be some twenty years before being profitable.

The law also provides for the erection of stone or other protections from landslips where trees are not applicable. The principal works of this class are on the Alpine range, and especially on the southern side, which is always found to be steeper and more devoid of vegetation than the northern side, and more favourable for the growth of the vine. Cross walls of dry-stone are built across the gulleys, in order to form level ground for its cultivation, and to protect it against the landslips caused by the water on these steep mountainsides.

In Valtellina (Lombardy), these works are very ancient, and are executed on a large scale. They follow the course of the valley, and are made of thick stone walls, with a heavy coping stone placed edgeways, and with a well-built stone apron where the water falls. Their number, position, and dimensions vary according to circumstances; and as they were built before the trees were cut down they are now more than ever necessary. In the Apennines, as well as the Alps, they are used to prevent landslips, and in 1684 Viviani reported on their necessity on the banks of the Arno to protect its bed from further silting up. In Florence the bed has not changed, but in the upper and mountainous part of the river it has risen considerably, and caused great damage to the surrounding lands in flood seasons. For such rivers these works are of use in keeping back the slips and preventing accumulations in their beds, whereas in large rivers with deep courses, all the silt, &c., brought down by the floods is washed out to sea and deposited at the mouth.

J. K. R.

Landslip at the Horgen Station, near Zurich.

(Die Eisenbahn, October 1, 1875.)

From the summit-level of the Zurich Left Shore railway, 1,434 feet above the sea, or 95 feet above the mean water-level of the lake, the line falls towards the latter with a gradient of 1 in 147,

and runs parallel to the shore until reaching Horgen Station. The station yard is about 440 yards in length; half its area, comprising goods shed and station building, is natural ground, and the remainder is embankment; and of the sunk portion of the yard, between the platform and the goods shed, about two-thirds was on the natural and one-third on made ground.

On the morning of the 22nd September, a subsidence of a few inches being observed, the traffic was stopped; notwithstanding which, at eleven o'clock the retaining wall and a portion of the plateau sank, while deep concentric cracks made their appearance in the latter. The subsidence extended as far as the station building, three sides of its foundations being laid bare and washed by water. About half of this slip was composed of natural ground. The difference between the original rail-level and the present surface of the sunken ground, amounts to about 52 feet as measured at the centre line of the railway from whence the slip falls gradually towards the lake, extending to a distance of 208 yards. The quantity of earth which has slipped may be estimated at about 261,600 cubic yards, corresponding to a weight of 360,000 tons, half of which would be natural ground; and it is open to question, whether, and to what extent, the subsidence may have been caused by vibration arising from the train traffic, considering that the weight of a train would only amount to $\frac{1}{2500}$th of the mass of earth which has given way.

If the substrata are composed of sandstone, overlying marl-shale, the latter, softened by time, may have been washed away by the waters of the lake, thereby depriving the superstratum of its support. But it will be difficult to discover the precise point at which the rupture originated, especially as it would probably be below the water-level.

When the trial borings for the pile foundations of the station building were made, to a depth of 59 feet, the rock was not reached; the promontory on which the station yard is situated was already retained on three sides by walls, and numerous landslips had occurred in the neighbourhood. The ground therefore seems to have been hardly suitable for a railway.

D. G.

Bridge over the Neva at St. Petersburg.

(Deutsche Bauzeitung, October 16, 1875, p. 416.)

In the course of last summer the erection of the new Liteini-Bridge over the Neva was commenced with great vigour. The material is wrought iron; the total length, 1,483·5 feet. The spans will be as follows: one of 244·3 feet, two of 213·6 feet, two of 196 feet, two of 175 feet, and a swing-opening of 70 feet. All the piers, with the exception of the one next to the left bank, will rest

on pneumatic foundations, and seven of them will have oval caissons 87·5 feet long by 20·7 feet broad, while the one on the right bank, bearing the swing bridge, will be 122·3 feet by 52·5 feet. The cylinders of wrought-iron plates, 0·236 inch thick, 6·9 feet long by 3·5 feet broad, as also the smaller cylinders for ingress and air, are put together on the spot, and the former are strutted internally and at intervals of 4·9 feet with horizontal irons in the form of a St. Andrew's cross. All the cassions are sunk to 42 feet below the bed of the river, the depth of which is also 42 feet, and as they rise to 6·9 feet above the surface, the entire height of the piers exceeds 90 feet. The workmen will probably have to work under a pressure of 4 atmospheres.

The bed of the river is composed of 17·4 feet of alluvial mud, 6·9 feet of marl and sand mixed, 6·9 feet of layers of sand and a final stratum of Silurian clay. The right pier is being erected on a framing of piles 52·5 feet long. The left is being built partly on pile-framing, partly on a caisson, which latter at the time of the report had been floating for several days, being kept in position by six huge air-bags. The masonry in the caisson was at that time nearly 10 feet high, and pneumatic work would begin as soon as the bottom was reached. The piles are being driven by machines of various kinds, worked by hand, steam, and horses; while one of English construction is moved by steam and gunpowder, and is said to be able to ram one hundred piles a day. Hitherto, however, it has gained no reputation for either cheapness or peculiar efficiency.

The engineer who has undertaken the work for the St. Petersburg town council, for £582,000, is Colonel Amandus von Struve, of the Imperial Engineer Corps, who has already gained a great reputation in Russia for similar works. A technical commission, chosen by the town council, watches the fulfilment of the specifications. The bridge is to be ready for traffic in the autumn of 1877. Colonel von Struve is at the same time engaged on the construction of a similar bridge for the Orenburg railway over the Wolga.

J. D. L.

The Shifting into Position of the Girders of the Quay Bridge, North-West Railway (Austria).

(Centralblatt für Eisenbahnen und Dampfschifffahrt, No. 103, Sept. 21, 1875.)

At the time of the construction of the Danube Bridge, of which the above forms one span, the river embankment (regulating) works at this point were not sufficiently advanced to allow of the erection of the girders for the last bay, viz. the Quay Bridge, and a temporary timber bridging was put up.

Parallel with the latter, and resting upon the stone piers, the

permanent girders were erected with the superstructure complete, and it then remained to substitute the permanent for the temporary bridge. The dimensions were—

Span of the bridge		269·5 feet.
Extreme length of girders		284·3 „
Depth of girders		24·6 „
Distance between girders		15·5 „
Weight of girders	about	280 tons.
Total weight to shift	„	310 „

The shifting of the girders through a lateral distance of 19·7 feet was effected during the cessation of traffic between the hours of 9.30 P.M. and 7.30 A.M. of the night of the 13th–14th September.

Previous to the erection of the girders two ways had been laid from pier to pier, across which rails, in pairs, of a strong section, bolted through and connected together by steel bolts of rectangular section, 19·6 inches apart, were fixed, each pair of rails being screwed and spiked down to bearers of oak. By these bolts the parallel position of the rails was insured, and fixed points provided for the screw jacks to butt against. Each pair of rails carried two cast-iron wagons, supporting the girders. These wagons were each provided with two rollers of Bessemer steel, strengthened in the middle, so as to serve for guide rings.

The body of each wagon was made in three pieces, bolted together over the axles, which permitted the parts to be separated and withdrawn without necessitating the raising of the girders.

The shifting was effected by specially-designed screw jacks, of which one was used at each end of the bridge. They were constructed with cast-iron bodies which could be slid along the rails, similar to the saddle of a lathe, and made fast, by a hook and key, to the steel bolts connecting the rails. The screw was of steel, 4 inches in diameter, with a screw pitch of $\frac{3}{4}$ inch, carrying a head made in one piece with it. On this again was fitted a disc free to revolve, forming the portion butting against the wagon carrying the girder. At the middle of the head was a toothed wheel, to which was connected a lever 6·6 feet long, with a cross arm passing through it, worked by six men.

The length of the screw spindle allowed of a shifting of the girder to the extent of 1·7 foot each working. When this had been effected, the screw was withdrawn, the screw jack slid to the next forward steel bolt, and the operation repeated. To avoid an unequal shifting of the griders, a scale was laid down at each end, by which the amount of progress could be observed.

After twelve shifts, the bridge was brought over its ultimate bed, and it was then necessary to raise the girders $\frac{3}{4}$ inch for the purpose of introducing the bed-plate rollers, and afterwards to lower them to the same extent. This was effected by means of two cast-iron wedges inserted under the ends of each girder, and connected together by a screw spindle attached to the heel of each, forming

the temporary bed of the bridge after the removal of the wagon, so that it only remained to lower the girders on to their permanent bed. With this object, the screw spindle connecting the wedges was made with a right and left handed thread at either end, by turning which the wedges were separated laterally, and the bridge allowed to sink into its permanent position.

The whole apparatus was designed by Mr. Seehann, Chief Engineer to the "Wiener Maschinen- und Waffenfabriks-Gesellschaft," by whom the bridge was constructed and the above operation conducted.

D. G.

On the Speed of Railway Trains. By A. VON BORRIES.

(Organ für die Fortschritte des Eisenbahnwesens, vol. xii., part vi., pp. 232–235, 1 pl.)

In order to preserve the locomotive engine and boiler, and to reduce as much as possible the consumption of fuel, it is desirable that the pressure of steam, its quantity produced per minute, and hence the condition of the fire, should be the same throughout the line. This requirement can be fulfilled if the speed of the train be varied according to the gradient of the line, in such a way that the product of the number of revolutions with the quantity of steam admitted into the cylinder per revolution remains constant.

The result of this is an equation in which the point of cut-off is expressed through the speed of the train. As the point of cut-off is also determined by the resistance of the train, which again depends on the speed and the gradient, a second expression for the cut-off is obtained, which combined with the first gives an equation between the speed, the gradient and those constants which are particular to the engine and train.

If this equation be expressed for trains of different description in a graphical way, a diagram may be obtained which will prove useful in the design of railway time tables.

G. KA.

On the Cost Price of Conveyance by Railways belonging to an Austrian Company. By M. BAUM.

(Annales des Ponts et Chaussées, October 1875, pp. 422–481.)

The nature of the country through which the railway passes, the method of construction, the prices of labour and materials, and other circumstances, affect the cost price of conveyance, which accordingly varies considerably on different railways.

Note.—The cost of working these Austrian railways seems excessive as compared with English railways.—SEC. INST. C.E.

The Author confines his remarks to the lines belonging to an Austrian company. The original line of the company was composed of two separate sections; one going from Brunn, by Prague, to Bodenbach; the other from Marchegg, by Pesth, to Basiasch. A new line, opened in 1870, unites these two sections, going from Brunn, through Vienna, to Marchegg; making a total length of line of about 930 miles.

The cost price of conveyance may be separated into five divisions, viz.: 1, working expenses; 2, management; 3, public charges and pensions; 4, taxes; 5, interest and redemption of capital. Again, the expenses of conveying passengers and goods must be separated under two heads: 1, expenses previous to, and subsequent to conveyance, independent of the length of journey; 2, cost of conveyance, which varies with the distance; so that if c is the cost of conveying a passenger L miles; P the cost before and after transmission; P′ cost of transmission,

$$C = P + P' L;$$

and for goods, using a ton as the unit,

$$c = p + p'(1 + w)l,$$

where w is the dead load carried expressed in tons.

By the aid of these equations, and others deduced from them, a series of tables has been drawn up, containing the results of each year from 1865 to 1873 for the old line, and from 1870 to 1873 for the new, from which the following facts are obtained. The expenses, independent of the length of journey, are, on the average, one-fifth of the whole; but this proportion is gradually increasing, having been less than one-sixth in 1866; the cost of the passenger service forms about one quarter of the total expenditure. On the old line the cost, independent of distance, for each passenger is 7½*d.*; on the new line 11*d.*; and the average cost of conveyance of each passenger per mile is 0·581*d.* on the old line, and 0·994*d.* on the new. The average passenger journey is 43½ miles for the nine years on the old line, decreasing from 50 miles in 1865 to 32 miles in 1873; on the new line it is 31 miles. The average total cost price for each passenger per mile on the old line is 0·764*d.*, and the receipt 0·856*d.*, giving a surplus of 0·092*d.*; on the new line, however, the receipt which is 0·994*d.*, shows a deficit of 0·351*d.* on the cost. The dead weight drawn per passenger is 0·546 ton, which is more than five times the weight reckoned for a passenger and his luggage. If all the carriages were filled the dead weight per passenger would be reduced to 0·2 ton; and the cost price of conveyance would be reduced 71 per cent. On an average about one-third of the seats are occupied. The average cost per passenger train mile for the old line is 6*s.* 1½*d.*, and for the new line 7*s.* 11½*d.*; the receipts being 6*s.* 10½*d.* and 5*s.* 10½*d.* respectively. The average number of passengers per train is 96·6 on the old, and 71 on the new line.

The cost of loading and unloading a ton of goods is, on the average, 1*s.* 2½*d.* The cost of conveyance of a ton (goods and wagon) per mile is 0·249*d.* on the old line, and 0·342*d.* on the new. The total cost price of the transport of a ton of goods per mile is 0·788*d.* and 1·16*d.* on the old and new lines respectively; the receipts being 1·166*d.* and 1·222*d.* The average dead weight drawn per ton of goods is 1·524 ton on the old line, and 1·638 ton on the new; the wagons are, on an average, not quite half loaded with the weight they could carry. The average cost per goods train mile is 9*s.* 5*d.* for the old, and 11*s.* 4*d.* for the new line; the receipts are 12*s.* 9*d.* and 10*s.* 5*d.* respectively. The average load of goods on a train is 141 tons on the old, and 112 tons on the new line.

The cost of construction of the old line was considerably less per mile than of the new line; also the steepness of the inclines, and the sharpness of the curves render the working expenses of the new line much heavier; and to these circumstances is due the very marked difference in the cost price of conveyance on the old and new lines.

The sum devoted to the payment of interest on capital on each line somewhat exceeds in amount the total working expenditure.

L. V. H.

Financial Relations between the State and the six principal Railway Companies in France. By M. DE LABRY.

(Annales des Mines, part 3, 1875, pp. 483–625.)

In June 1873 the Minister of Public Works addressed a circular to the officials connected with railways and other works, stating that communications had been made to him by the railway companies as to the increased cost of maintaining the railways, owing to the substitution of steel for iron rails, necessitating modification of the accounts between the State and the companies. The minister asked the officials to report to him on the following three questions:—

1. Whether the clause of the convention relating to additional works authorised the charging of the cost of substitution of steel for iron rails, and of other improvements, to the account of the first establishment.

2. Should this be admitted, what would be the *modus operandi* of estimating this increased cost.

3. What would be the consequences to the financial relations between the State and the companies.

In reply to these questions, M. de Labry presented a report to the minister, in which he considered the subject under the following heads:—

1. The general conventions between the State and the railway companies.

2. The methods by which the companies raised their loans.
3. The consequences to the State and to the companies of the different modes of attributing the expenditure.
4. The variations in the price of rails and other materials.
5. The apportionment of the expenditure on improvements between the accounts of construction and maintenance, especially as regards the substitution of steel for iron rails.

The first of these only is treated of in the present article.

Duration of Concessions.—The concessions for the six principal companies are for a term of ninety-nine years, the date of termination varying from 1950 in the case of the "Nord" to 1960 for the "Midi"; the mean date being the end of the year 1956.

Dates of Conventions.—The principal conventions were concluded in 1857, 1858–9, 1863, and 1868–9, the whole being readjusted by the latter conventions—viz., 1868–9. Partial modifications have been made since this date, but, in order to present the system as a whole, the relations between the State and the railways are described as existing in the year 1869.

The following tables (I., II., III., pp. 341, 342 and 343), compiled from upwards of twelve tabular statements in the Report, give in a condensed form the substance of the statistics and information furnished by M. de Labry.

Original Share Capital.—The total amount of this was 1,465,175,000 francs (£58,607,000), being issued originally at prices varying from 400 to 500 francs, and bearing dividends varying from 30 to 50 francs per share. These prices and dividends were fixed by the conventions. In Table I., col. *c.*, is shown the amounts of these dividends given as percentage on the price of issue.

Bonds of Old System.—The companies were allowed by the State, in addition to their share capital, to issue bonds, to be amortised during the term of concession, the interest and annual sinking-fund of which should amount to 5·75 [1] per cent., the companies benefiting, or otherwise, according as the state of the money market allowed them to be issued above or below par.

Bonds of New System.—The State guarantees to the companies during fifty years from the 1st January, 1865,[2] interest at 4 per cent. per annum, and a corresponding annual sinking-fund (0·65 per cent.) on the expenditure of the new system; but it is stipulated that if the net receipts of the old system should exceed the mean kilometric revenue, or 'déversoir' (see Table I., col. *g*), the balance should be added to the receipts of the new system, to assist in paying the interest and sinking-fund of that system.

Reserved Revenue, or 'Déversoir' of Old System.—This consists of the dividends due upon the original share capital, the interest, and sinking-fund of the bonds of the "old system" (5·75 per cent.), and 1·10 [3] per cent. interest upon the bonds of the "new system,"

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[1] Le Nord, 5·50 per cent. [2] January 1st, 1864, for the "Est."
[3] Le Nord, 0·85 per cent.

TABLE I.—[illegible], ACCORDING TO CONVENTIONS OF [illegible]

Name of Railway.	a. Length. Old System.	a. Length. New System.	a. Length. Total.	b. Original Share Capital of "Old System."	c. Rate of Interest on Shares, based on price of Issue.	d. Amount of Bonds, including "Additional Works" (limited).	e. Total authorised Capital (b + d).	f. "Reserved Revenue" for conceded Lines.	g. "Reserved Revenue" for conceded Lines per Kilomètre of "Old System."
	Kilomètres.	Kilomètres.	Kilomètres.	Francs.	Per cent.	Francs.	Francs.	Francs.	Francs.
[illegible]	994	2,123	3,117	292,000,000	6·00	938,000,000	1,230,000,000	28,932,500	29,100
[illegible]	798	1,771	2,569	146,300,000	5·06	634,700,000	781,000,000	22,316,000	28,010
[illegible]	1,174	650	1,824	231,875,000	11·84	568,125,000	800,000,000	44,896,875	38,240
[illegible]ns.	2,020	2,340	4,360	300,000,000	10·10	1,068,000,000	1,368,000,000	52,537,000	26,000
Ouest	900	1,994	2,894	150,000,000	5·90	1,118,000,000	1,268,000,000	32,309,000	35,900
Paris-Lyon-Méditerranée	4,845	1,756	6,101	845,000,000	10·88	2,412,000,000	2,757,000,000	138,522,500	31,900
	10,231	10,634	20,865			6,738,825,000	8,204,000,000	319,513,875	
Victor Emmanuel	..	144	144	..		95,629,712	95,629,712		
Total	10,231	10,778	21,009	1,405,175,000		6,834,454,712	8,299,629,712		

h. [illegible]	i. [illegible]	j. Net Revenue at which division of Profits with the State commences.	k. Net Revenue at which division of Profits with the State commences, per Kilomètre.	l. Rate of Interest on original Shares at the time of division of Profits, after paying Interest on Bonds.	m. Value of Subventions by the State.	n. Local Subventions by Departments, &c.
[illegible]	[illegible]	Francs.	Francs.	Per cent.	Francs.	Francs.
[illegible]	[illegible]	[illegible]	26,019	9·30	190,652,153	7,038,864
[illegible]	[illegible]	[illegible]	23,917	17·00	255,516,561	21,223,336
[illegible]	[illegible]	[illegible]	[illegible]	13·73	21,463,112	3,868,63[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	15·38	339,155,133	8,937,314
[illegible]	[illegible]	[illegible]	[illegible]	13·43	284,7[illegible],149	14,341,135
[illegible]	[illegible]	[illegible]	[illegible]	14·4[illegible]	479,129,982	32,654,7[illegible]
[illegible]	[illegible]	[illegible]	[illegible]			
[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]

[illegible]

TABLE II.—SUMMARY STATEMENT of SHARE CAPITAL and BONDS of the ENTIRE SYSTEM of FRENCH RAILWAYS ACCORDING to CONVENTIONS of 1868–9.

Description of Shares and Bonds.	—	Grouped in three different ways, as under.	
	Francs.	I.	Francs.
Original shares of "Old System," 3,059,000 in No. at 482·18 average price.	1,465,175,000	Shares . .	1,465,175,000
Bonds of "Old System" .	2,657,825,000	Bonds. . .	6,834,454,712
	4,123,000,000	Total . .	8,299,629,712
Bonds of "New System" guaranteed by the State up to 4·65 per cent. . .	3,702,000,000	II.	
		"Old System"	4,349,000,000
Total capital of the "First Establishment" . . .	7,825,000,000	"New System"	3,855,000,000
		Victor Emmanuel railway. . .	95,629,712
Additional Works.		Total . .	8,299,629,712
"Old System" 226,000,000 "NewSystem" 153,000,000	379,000,000		
		III.	
	8,204,000,000	Guaranteed by the State	3,950,629,712
Bonds of the Victor Emmanuel railway . . .	95,629,712	Not guaranteed	4,349,000,000
Total capital . .	8,299,629,712	Total . .	8,299,629,712

to compensate for the difference between 4·65 per cent. guaranteed by the State and 5·75 per cent. actually paid by the companies to the bondholders. The reserved revenue amounts altogether for the six great companies to 319,513,875 francs (£12,780,554), (see Table I., col. *f*).

Additional Works (*Limited*).—The amount authorised to be expended on the additional works of the old system during a term of ten years, such as enlargement of stations, the laying of second lines or sidings, increase of rolling stock, &c., is limited in the case of each railway, the total amount being 226 million francs,[1] the reserved revenue being increased by the amount of 5·75 per cent. on this expenditure (*vide* Tables II. and III.); and to the "new system" the same principle applies, the authorised amount for

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[1]

Est	40	millions.
Midi	30	"
Nord	60	"
Paris-Lyon-Méditerranée	96	"
Total	226	"

TABLE III.—SUMMARY STATEMENT of INTEREST upon the CAPITAL of ENTIRE SYSTEM, ACCORDING to CONVENTIONS of 1868–9.

Description of Shares and Bonds.	Rate of Interest and Sinking Fund.	Amount of Interest.	Grouped in three different ways.	
	Per cnt.	Francs.		
Original share capital	8·90[1]	130,200,000	I.	
Bonds of "Old System"	5·75	149,091,875		Francs.
" "New System" (supplementary interest	1·10	40,222,000	Interest upon shares	130,200,000
			Interest upon bonds	388,218,261
"Reserved Revenue" of conceded lines	..	319,513,875		518,418,261
Additional Works of—			II.	
"Old System"	5·75	12,845,000		
"New System" (supplementary interest)	1·10	1,606,000	Interest upon capital of "Old System"	292,136,875
Total "Reserved Revenue" for conceded lines and additional works	..	333,964,875	Interest upon capital of "New System"	221,085,500
			Victor Emmanuel	5,195,886
Guaranteed Interest.				518,418,261
Bonds of "New System"	4·65	172,143,000		
Bonds of "New System" (additional works)	4·65	7,114,500	III.	
			"Reserved Revenue"	333,964,375
		513,222,375	Interest guaranteed by the State	184,453,386
Bonds of the Victor Emmanuel railway	..	5,195,886		
Total interest	..	518,418,261		518,418,261

[1] Average rate.

additional works being 153 million francs.[1] Of this the Government guarantee 4·65 per cent., as in the case of the other bonds—an addition of 1·10 per cent. on this amount being added to the reserved revenue of the old system to make up 5·75 per cent. (*Vide* Tables II. and III.)

Total Reserved Revenue.—It will be seen from Table I. that this amount, increased by the addition of interest on the capital for

[1] Orléans . . . . 22 millions.
Ouest . . . . 124 "
Paris-Lyon-Méditerranée . . . . 7 "
Total . . . . . . 153 "

additional works (limited) amounts to 333,964,875 francs. (See Table III.)

Total Interest guaranteed by the State.—This amounts to 184,453,386 francs, and consists of interest and sinking-fund at 4·65 per cent. upon the bonds of the new system—including the additional works of that system—and the bonds of the Victor Emmanuel railway. (*Vide* Table III.)

Total Amount required to pay Interest on Bonds and Dividends on Share Capital arranged by Conventions.—This is the sum of the two last-mentioned amounts, viz., the total reserved revenue plus the guaranteed interest, and amounts to 518,418,261 francs. (*Vide* Tables I. and III.)

Net kilometric Revenue at which the guarantee of the State ceases.

When the account of the first establishment is finally closed, if the total net revenue of both systems should not amount to the sum of the reserved revenue and the guaranteed interest, *i.e.*, to the total interest required for the shares and bonds, the State will have to make a further advance to the companies. On the other hand, when the revenues of both systems amount to this sum, the State will begin to be repaid its advances, with simple interest at 4 per cent. This limit of revenue for the entire system is 518,418,261 francs. (*Vide* Table I., col. *h*, also Table II.)

Additional Works "not limited."—After the term of ten years indicated for the execution of the additional works "limited," the companies are empowered to execute further works, to be charged to the account of the first establishment; but neither the guarantee of the State nor the reserved revenue will be increased on this account. The payments of interest and sinking-funds on these expenses will, however, be paid out of the revenue of both systems before the division of profits with the State takes place.

Division of Profits with the State.

This will take place when the net revenue of each company attains a certain amount. (*See* Table I., col. *j*.)

These amounts were fixed for each company by the conventions of 1868–9, different rates of interest being taken for each company. For instance, for the Est it is fixed at 8 per cent. for the entire capital of the old system, and 6 per cent. for the new system. On the average for the entire system it is fixed at about 7¼ per cent. on the capital of all the shares and bonds. This division of profits, however, will not take place until the repayment to the State has been effected of all the sums advanced by it previously as guaranteed interest. The interest which the original shareholders will receive at the time of division of profits with the State is shown in Table I., col. *l*.

Subventions by the State.—The State has granted subsidies to the railway companies in various ways (not to be repaid, as in the case

of the guaranteed interest), either by actual payments, by enabling the companies to borrow money on the security of State annuities, by the execution of works, or by grants of land. The amounts of these subsidies, reduced to money value, are shown in Table I., col. *m*.

The companies also received subsidies from the departments, and other local bodies, to the amount of about 88,000,000 francs. The amounts of these subventions are shown in Table I., col. *n*.

Expiration, Redemption, or Forfeiture of Concessions.

Expiration.—During the last year of the concession the State will have the right to appropriate the revenues of the companies, for the purpose of defraying the cost of putting the lines and works in good repair.

At the expiration of the term of the concession the State will enter into full possession of the lines and works, but paying the company for the rolling stock, &c., on a valuation.

Redemption.—At any time after the first fifteen years the State has the right to redeem the concession by the payment of an annuity during the remainder of the term; such annuity to be estimated on the average of the net receipts of the preceding seven years, the two worst years being omitted from the average; but in no case will the annuity be less than the net receipts of the last year.

Forfeiture.—In any case of the non-fulfilment on the part of the companies of the requirements of the conventions, either in regard to the construction or the working of the line, the State has a right to terminate the concession and sequestrate the company's property by putting it up to public auction.

Term of the Guarantee.—After the expiration of fifty years from the commencement of the guarantee, the State ceases to make any advances to the companies, whatever may be the receipts.

Modifications introduced into the Convention since the year 1869 *up to the end of* 1874.—The only alterations of importance are due to the concession of part of the Est railway to Germany. The consequences of this and other slight modifications are that the total mileage is reduced from 21,009 to 20,617 kilomètres. The total capital at the end of 1874 stood at 8,085,229,712 francs, as against 8,299,629,712 francs at the end of 1869 (*vide* Table I., col. *e*). Also the value of the subventions by the State at the end of 1874 amounted to 1,617,136,951 francs, as against 1,590,636,954 francs in 1869 (*vide* Table I., col. *m*).

Principal Financial Results of the Conventions. Payment of Guaranteed Interest by the State.—The Nord and the Paris-Lyons-Mediterranean Companies did not find it necessary to have recourse to the guarantee, and the other four large companies required only in the year 1869, 25,058,041 francs, the total guaranteed interest being 184,453,386 francs (*vide* Table III.). The net receipts showed a steady increase, and it was estimated that by the year 1884 the

payment of guaranteed interest would entirely cease, and the repayment to the State commence.

It appears that the Government, in the years 1871–2, adopted the plan of paying the guaranteed interest by terminable annuities, spread over the whole term of the concession, as in the case of some of the subventions, and this mode of payment was accepted by all the companies except the Ouest. In the year 1873, however, the State again returned to the system of cash payments, and the amount paid in the year 1873 was 34,800,000 francs.

Subventions by the State.—The subsidies by the State in money amount to about 600,000,000 francs, chiefly paid by means of terminable annuities. The total value of subventions, including grants of land, &c., is given in Table I., col. *m*.

Additional Works (limited).—The companies were authorised by the Conventions of 1868–9 to expend 379,000,000 francs on these works (*vide* Table II.). Up to the year 1874, however, they had actually only expended 174,583,230 francs of this amount, leaving a disposable balance of 204,416,769 francs.

Dividends on the Ordinary Shares.—In the year 1873 these were considerably above the rates of interest arranged by the conventions given in Table I., col. *c*. The companies have also established reserved funds, amounting in the aggregate to nearly 4½ per cent. on the original share capital.

C. J. B.

Annular Iron Sleeper Permanent Way. By P. Chopin.

(Annales Industrielles, Nov. 7, 1875, pp. 586–590, 2 pl.)

As showing the necessity of an efficient and economical iron permanent way, the Author states that the railways of France alone annually require 106 million cubic feet of timber, and as the requirements of other countries are equally great in proportion, the enormous drains upon the timber resources of the world must so enhance the price of wood that some more durable material will have to be used for sleepers. The nature and form of this material are therefore of great importance. The conditions of sufficient surface upon the ballast; sufficient resistance to displacement by the mass buried in the ballast; elasticity; simplicity of the system and of fastenings; facility of laying and taking up for renewals; economy of first cost, and facility of manufacture, are met, it is submitted, by the following designs of M. Chopin, for a gauge of about 4·75 feet (1·45 mètre), using Vignoles rails of from 55 lbs. to 66 lbs. per yard. The sleepers consist of a ring 15·75 inches in diameter of 2-inch equal angle iron, 0·236 inch thick. The two ends of the piece of angle iron from which the ring is turned overlap, and between these two ends the tie or stretcher bar, also of angle iron, is placed, and the three thicknesses are secured by one rivet 0·7 inch in diameter. The tie bar, which occupies a transverse diameter of each sleeper, is secured at its extremity

by a similar rivet to the horizontal wing of the angle-iron ring. The rail fastenings consist, on each sleeper, of only two L-headed rivets, and these, as well as the tie rods, are fastened into the sleepers before they leave the works, so that no small or separate pieces, such as bolts, &c., are needed in the laying of the line, except of course the fish-plate bolts. The method of laying the line, and the manner in which the rails are gripped, are as follows.

The pair of rails is supported upon two pieces of small timber, the sleeper with its tie bars being free of the rails, is turned on its centre, until the rivets firmly grip the rails. When each pair of sleepers is so fixed, the pieces of timber are removed, and the sleepers dropped into the small excavations made to receive them, which are then filled in and rammed up with ballast composed of broken stones and sand. Each 20-feet rail is supported by five sleepers placed 4·3 feet apart from centre to centre, the two sleepers of adjoining rails being 2·6 feet from centre to centre, this disposition giving 2·95 feet of unsupported rail between the sleepers, and about 16 inches at the fish-plates. A pair of sleepers, with tie bar and rivets, weighs 44 lbs., and for a first-class railway 61·6 lbs., the angle iron of the sleepers weighing respectively 2·85 and 4 lbs. per foot. A short piece of line (60 feet) has been laid on the railway from Bordeaux to La Sauve, since May last, with 66-lb. rails and sleepers, weighing 44 lbs. per pair with tie rod, and as yet no alterations have been found necessary.

Its advantages over other systems of iron sleepers are:—Simplicity of construction, absence of all loose and small pieces, and facility of laying and taking up.

A comparison between the cost of this and an ordinary wood road shows an economy of about £200 per mile of single line, taking into consideration the relative cost of maintenance.

W. W. B.

On the Fixing of Railway Tires. By W. Clauss.

(Organ für die Fortschritte des Eisenbahnwesens, vol. vi., pp. 235–238.)

The cause of the frequent accidents with railway tires lies chiefly in the use of Bessemer steel, the quality of which is not always perfectly homogeneous and reliable. Besides defects in the material, the method of fixing the tire with one set screw, the use of disc wheels instead of spoke wheels, and the forced appliance of the break, also induce accidents.

The best and safest method of fastening the tire is that with retaining rings, as may be seen by the subjoined account of experiments made with a wheel so constructed.

A spoke wheel with Mansell's retaining rings, after its tire had been cut open in radial direction, was put under a goods van, and the latter was run for eight days coupled with a shunting engine.

The distance between the two sections of the tire was found after that time to be exactly the same as immediately after the cut was taken. The tire being cut in another place, the wheel was again run for five days, and after making a third cut it was run with 37 miles' velocity for 30 miles, without the distances between the sections having varied.

In order to try the resistance of the fastening sideways, the wheel was then laid under a monkey of 13¾ cwt. and 10 feet fall. The first blow broke two of the bolts, and the second loosened the segments of the tire and bent the retaining rings.

This trial, as well as others made on the Berlin-Potsdam-Magdeburg railway, and on many lines in England, show that the fastening of tires with retaining rings is a preventive of accidents.

The cost of two retaining rings, twelve bolts, and necessary fitting work is 25*s*. per wheel, whilst the cost of the ordinary set screw is 4*s*., and that of a bolt going through tire and felly 6*s*. per wheel. As the retaining rings as well as the bolts can be used again, the expense of fixing renewed tires is very small.

G. Ka.

Form of Channel of Constant Mean Velocity. By F. E. Rose.

(Roorkee Professional Papers on Indian Engineering, July 1875, pp. 211–216.)

To calculate the contour for the cross section of a channel, such that for all depths (x) of water running in it with a given declivity (p), the mean velocity (v) of the current shall be constant: take the centre of the channel bottom for the origin of the coordinates, x the depth of water, y the corresponding half-width of the channel.

In the formula for the velocity in open channels, $v = n\sqrt{p\frac{s}{c}}$ substitute the general expressions for area and arc,

$$s = 2\int y\,dx \qquad c = 2\int\sqrt{1+\left(\frac{dy}{dx}\right)^2}\,dx\,;$$

and reducing

$$v^2\int\sqrt{1+\left(\frac{dy}{dx}\right)^2}\,dx = n^2 p\int y\,dx.$$

Differentiating and putting $\frac{n^2 p}{v^2} = n_1$,

$$dx = \frac{dy}{\sqrt{n_1^2 y^2 - 1}} \quad . \; . \; . \; . \; . \; . \; . \quad (1)$$

(y cannot be less than $\frac{1}{n_1}$, or this becomes imaginary.)

Integrating, the limits being $\frac{1}{n_1}$ and y,

$$x = \frac{1}{n_1} \text{ hyp. log. } n_1 \left(y + \sqrt{y^2 - \frac{1}{n_1^2}}\right)$$

Converting hyperbolic into ordinary logarithms and giving n_1 its value,

$$x = \frac{2 \cdot 30258\, v^2}{n^2 p} \log. \left\{\frac{n^2 p}{v_2}\left(y + \sqrt{y^2 - \frac{v^4}{n^4 p^2}}\right)\right\}$$

putting $\quad a = \dfrac{n^2 p}{2 \cdot 30258\, v^2} \quad$ and $\beta = \dfrac{v^2}{n^2 p} \quad . \quad . \quad . \quad (2)$

$$x = \frac{1}{a} \log. \frac{y + \sqrt{y^2 - \beta^2}}{\beta};$$

whence $y = \dfrac{\beta}{2}\left(\dfrac{1}{\log.^{-1} ax} + \log.^{-1} ax\right) \quad . \quad . \quad . \quad (3)$

which is the equation required.

From (1) and (2)

$$dx = \frac{dy}{\sqrt{\frac{y^2}{\beta^2} - 1}}$$

Area $\quad = 2 \displaystyle\int_\beta^y y\, dx = 2 \int_\beta^y \frac{y\, dy}{\sqrt{\left(\frac{y^2}{\beta} - 1\right)}} = 2\beta \sqrt{y^2 - \beta^2}$

from (3)

$$s = 2\beta^2 \sqrt{\left\{\frac{1}{4}\left(\frac{1}{\log.^{-1} ax} + \log.^{-1} ax\right)^2 - 1\right\}}$$

$$= \beta^2 \left(\frac{1}{\log.^{-1} ax} - \log.^{-1} ax\right).$$

Also $\quad l = \text{length of arc} = \displaystyle\int_0^x \sqrt{1 + \left(\frac{dy}{dx}\right)^2}\, dx.$

But $\quad \left(\dfrac{dy}{dx}\right)^2 = \dfrac{y^2}{\beta^2} - 1 \quad$ and $\quad dx = \dfrac{dy}{\sqrt{\frac{y^2}{\beta^2} - 1}}$

Therefore $\quad l = \displaystyle\int_\beta^y \frac{y\, dy}{\sqrt{y^2 - \beta^2}} = \sqrt{y^2 - \beta^2}$

$$= \beta \sqrt{\left\{\frac{1}{4}\left(\frac{1}{\log.^{-1} ax} - \log.^{-1} ax\right)^2 - 1\right\}}$$

$$= \frac{\beta}{2}\left(\frac{1}{\log.^{-1} ax} - \log.^{-1} ax\right).$$

In equation (3) $x = 0$, then $y = \beta$. Hence the perimeter consists of a horizontal straight portion 2β, and the two curved portions each equal to l.

Thus

$$c = \text{perimeter} = 2\beta\left\{1 + \sqrt{\frac{1}{4}\left(\frac{1}{\log.^{-1} ax} + \log.^{-1} ax\right)^2 - 1}\right\}$$

$$= \beta\left\{\frac{1}{\log.^{-1} ax} - \log.^{-1} ax + 2\right\}.$$

Table of calculated half-widths at depths of 0, 1, 2 . . . 10·8 feet of a channel of which the slope is 0·0004, and the mean velocity 3·5 feet per second.

Depths . .	0	1	2	3	4	5	6	7	8	9	10	10·8
Half-widths .	3·33	3·5	3·9	4·7	6·0	7·8	10·3	13·7	18·4	24·6	33·3	42·9

A. T. A.

On the Distribution of Velocities in a Current.

By M. Bazin.

(Annales des Ponts et Chaussées, September 1875, pp. 309–351.)

The velocities of a current at different points on the same vertical line vary as the ordinates of a parabola: thus if v is the velocity at any point, at a depth d below the surface, d' the depth of the point of maximum velocity, V this velocity, and D the total depth,

$$v = V - M\left(\frac{d - d'}{D}\right)^2 \quad . \quad . \quad . \quad (1)$$

This law has been deduced from the results of numerous observations; and the value of M depends upon the position of the point of maximum velocity, which is generally at the surface, but sometimes below it.

Let u be the mean velocity on the vertical line, then

$$u = \int_0^1\{V - M(x - a)^2\}\, dx = V - M\left(\frac{1}{3} - a + a^2\right) \quad . \quad . \quad . \quad (2)$$

where $x = \frac{d}{D}$, and $a = \frac{d'}{D}$;

and it may readily be deduced that the velocity at half the depth differs from the mean velocity by only $\frac{1}{12}$ M. In experiments conducted upon very regular conduits, about 6·5 feet wide, the velocities were considerable, and in all but seven instances the maximum velocity was at the surface. The value found for M was $20\sqrt{DI}$,

I being the inclination of the conduit, so that equation (1) becomes

$$v = V - 20\sqrt{DI}\,x^2 \quad . \quad . \quad . \quad (3)$$

when the maximum velocity is at the surface; and by representing the results of the experiments graphically, taking the values of $\frac{V - v}{\sqrt{DI}}$ for ordinates, and the corresponding values of x for abscissæ, it was found that the locus of the points obtained was, approximately, a parabola the equation of which is $y = 20\,x^2$. When the maximum velocity is below the surface a different value must be given to M; the equation then is

$$v = V - 20\sqrt{DI}\left(\frac{x - a}{1 - a}\right)^2 \quad . \quad . \quad . \quad (4)$$

and the points obtained by a graphic representation approach closely to the parabola $y' = 20\,x'$. In a watercourse of considerable width, where the influence of the banks may be neglected, dividing both sides of equation (4) by the mean velocity u it becomes

$$\frac{v}{u} = \frac{V}{u} - 20\sqrt{A}\left(\frac{x - a}{1 - a}\right)^2$$

where $A = \frac{\Delta I}{V^2}$; Δ being the mean depth, and V the mean velocity throughout the section of the stream. Also substituting the new value of M in equation (2), it becomes

$$\frac{V}{u} = 1 + 20\sqrt{A}\,\frac{\frac{1}{3} - a + a^2}{(1 - a)^2}.$$

The value of $\frac{V}{u}$ in these experiments varied between 1·09 and 1·19.

Experiments conducted with a current-meter on the Saône, the Seine, the Garonne, and the Rhine showed similar results; but the observations taken near the bottom gave lower velocities than the parabolic law would indicate; possibly this was due to errors in the experiments, the current-meter being unable to furnish correct results near an uneven bottom. The value of $\frac{V}{u}$ varied generally between 1·1 and 1·13.

The experiments of Messrs. Humphreys and Abbot on the Mississippi led them also to infer the parabolic law; but the value of the parameter they obtained was very different from that deduced from the experiments on the European rivers, the minimum value of $\frac{M}{u}$

being 0·40 for the latter, whereas in the Mississippi experiments it is as low as 0·15. Also the value of $\frac{V}{u}$, which in the European rivers was never found lower than 1·1, was as low as 1·02 in the Mississippi. They give the following equation for the parameter:

$$M = \sqrt{u}\,\frac{0 \cdot 533}{\sqrt{D} + 0 \cdot 457};$$

and they infer from their experiments that the maximum velocity is always at a third of the depth. Mr. Gordon has lately made similar experiments on the Irrawaddy, but he finds that the maximum velocity is almost always at the surface. Representing the experiments on the Mississippi and the Irrawaddy graphically, it appears that the points obtained from the observed velocities nearly correspond with the theoretical parabola near the surface, and when the velocities are least rapid, but have a larger parameter; but in times of flood, and beyond half the depth, the parabolic form is lost; and this divergence is more marked in the Mississippi observations. The experiments on both rivers were conducted with an empty watertight barrel, weighted with lead, and sunk in the stream to the required depth, a cord uniting it to a surface float with a flag to indicate its position. The quicker motion given to the cord and surface float by the upper current, and the rising of the barrel in the eddying water into a mere rapid current, slackening the cord and setting free the surface float, probably account for the divergence between theory and observation. The nearer approach of the Irrawaddy experiments to the theoretical law is probably due to the connecting cord having been thinner than the one used on the Mississippi; and to the experiments being confined to one section, whereas those on the Mississippi were taken at different places, and with considerable differences in the velocity of the current.

L. V. H.

On the Use of the Screw Current Meter in Determining the Discharge of Streams. By F. Exner.

(Zeitschrift für Bauwesen, vol. xxv., parts 8–10, cols. 342–382.)

In 1863 measurements were taken to determine the dry-weather discharge of the Oder. To test the results a comparison was made of the calculated discharge for different sections through which the same volume was passing. It was found that the calculated discharge was always greater for the smaller sections than for the larger. The regularity of the difference permitted the conjecture that its cause was the frictional resistance of the instrument. The effect of this resistance is to prevent the rotation of the instrument

when the velocity falls below a certain finite value. The current meter used at Oppeln ceased to revolve when the velocity was reduced to 0·35 foot per second; and it was proposed to correct the discharges which differed from each other by adding to each the product of this velocity with the area of the corresponding section. Even then the results did not strictly agree.

By adding the discharge due to a velocity of 0·35 foot, only that part of the frictional resistance is taken into account which belongs to the instrument at rest. When rotation begins the friction is altered. The co-efficient of friction changes, the inertia of the instrument affects the indications and the resistance which the water opposes to the motion of the vanes. Suppose the so-called *value of a revolution*, or length of the part of the stream which passes the instrument during one revolution, is ascertained. This is commonly effected by drawing the instrument a distance δ in still water, and noting the number of revolutions, N. Then the value of a revolution is $W = \delta \div N$. But the value thus obtained is affected by the friction of the instrument. If it is used to determine the velocity of a stream, the effect of the friction is partly taken into account. If to the velocity thus determined that velocity is added which corresponds to the cessation of rotation, the process cannot lead to a true result.

In 1864 experiments were made to ascertain whether the value of a rotation was a variable function of the velocity. The current meter was fastened in front of a boat, which was towed at various velocities, and the number of revolutions in a distance of 200 feet was noted. The experiments showed that the value of a revolution varied with the velocity, and decreased as the velocity increased. The observations appeared to show that the value of a revolution did not fall below a finite value, even for an infinitely great velocity, and that that finite value was nearly reached at the higher of the velocities at which the experiments were made.

The Author assumes that the number of revolutions, N, is a function of the time, t, occupied in moving the instrument through still water the distance δ. That is, $N = F(t)$. At an infinite velocity, for which $t = 0$, N must still have a finite value. Let ν be that value. Then since t appears from the experiments to enter the equation in a higher power than the first, let

$$N = \nu - A t^2,$$

where A is a constant. This equation must fulfil the condition that $N = 0$ for some given velocity v_0. Let t_0 be the duration of the experiment corresponding to the velocity v_0,

$$0 = \nu - A t_0^2$$

Therefore $$N = \nu - \frac{\nu}{t_0^2} t^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Applying the method of least squares, the Author deduces

from seventeen experiments the following values for the constants:—

$$N = 62 \cdot 8351 - 0 \cdot 000129293\, t^2 \quad . \quad . \quad . \quad (2)$$

This is found to agree closely with the experiments, the errors being generally little greater than the unavoidable errors of observation. For great velocities it cannot be much in error, as in the experiments the values of N are nearly constant at the higher velocities. For lower velocities, however, the agreement is not quite so satisfactory. The equation (1) is the equation to a parabola. The true curve indicated by the experiments appears to be somewhat more sharply bent at low velocities than that parabola, and hence the Author infers that a quadrant of an ellipse would better agree with the experiments, the origin of co-ordinates being taken at the centre. In that case the major semiaxis of the ellipse would represent the time t_0, which corresponds to the velocity at which the instrument ceases to revolve; and the minor semiaxis would represent the number of revolutions corresponding to an indefinitely great velocity. Accordingly,

$$N = \frac{\nu}{t_0} \sqrt{(t_0^2 - t^2)} \quad . \quad . \quad . \quad (3)$$

Applying the method of least squares, and using the seventeen experiments,

$$N = 0 \cdot 1193 \sqrt{(280900 - t^2)} \quad . \quad . \quad (4)$$

This gives for the velocity at which the instrument would cease to revolve

$$v_0 = \frac{\delta}{t_0} = 0 \cdot 3774,$$

which closely agrees with the observed value for this instrument, $0 \cdot 3333$ foot.

For the value of a revolution, since $W = \frac{\delta}{N}$, $t = \frac{\delta}{v}$ and $t_0 = \frac{\delta}{v_0}$, there is obtained from (3)

$$W = \frac{\delta}{\nu} \sqrt{\frac{v^2}{v^2 - v_0^2}} \quad . \quad . \quad . \quad (5)$$

Let n be the number of revolutions in any time T, so that $N = \frac{n\,t}{T}$; then

$$v = \sqrt{\frac{\delta^2}{\nu^2\, T^2}\, n^2 + v_0^2} \quad . \quad . \quad . \quad (6)$$

which gives, directly, the velocity v, indicated by a meter, when the

number of revolutions is observed. Let T = 60 seconds, and using the constants in (4),

$$v = \sqrt{0 \cdot 00278\, n^2 + 0 \cdot 1424} \quad . \quad . \quad (7)$$

The Author shows that this equation agrees very closely with his experiments. As a confirmation he deduces from it the theoretical value of a revolution on the supposition that there was no friction to be overcome. He shows that that value is ($v_0 = 0$),

$$v = \frac{\delta n}{\nu T}$$

being constant at all velocities. The value thus obtained was found to agree with the pitch of the screw employed in the experiments.

Other formulæ which have been employed in reducing current meter observations are then examined. The ordinary formula,

$$v = v_0 + \frac{\delta n}{\nu T} = v_0 + b\, n,$$

is an equation to a straight line. It leads to errors whose maximum value may reach v_0. Of other formulæ the Author prefers Baumgartner's

$$v = a\, n + \sqrt{(b\, n^2 + c)},$$

an equation which differs from (7) only in the first term, and agrees with the experiments as closely as (7); but in use, and for the application of the method of least squares in determining the value of the constants, it is less convenient.

W. C. U.

Gauges for Registering Water Levels. By J. B. Chabaneix.

(Annales du Génie Civil, July 1875, pp. 393–406, 1 pl.)

The Author first describes an instrument of a well-known form, in which the rise and fall of a float due to the alterations of level of the stream registers the height of the water on a band of paper travelling on a pair of rollers driven by clockwork. He then gives details of a modification of the instrument, which the difficulty of obtaining suitable clockwork at Montpellier induced him to make. A small tube is fixed perpendicularly through the float, so that one end is always immersed in the water while it is maintained in a vertical position by two guides during the rise and fall of the water. The other end is bent at right angles for a short horizontal length, and then carried vertically downwards to a level

below that of the other end, thus forming a syphon, which draws water from the stream at a constant rate. The horizontal part of the syphon is carried between two parallel guides in the form of a helix, which cause it to rotate as it rises or falls. Below the mouth of the syphon is placed a series of small troughs, arranged in the form of a spiral staircase, and each communicating with a corresponding bottle. Thus when the syphon is in a certain position, the water discharged from it falls into one of the troughs and runs off into its corresponding bottle; if the level of the water in the stream rise, the float rises, at the same time the spiral guides cause the syphon to rotate and discharge into a different trough, the length of time during which the syphon remains in a given position, or what is the same thing, during which the water in the stream remains at the same level, being ascertained by the subsequent measurement of the contents of the corresponding bottle.

A. T. A.

Hydrometric Observations on the River Tiber.

By Angelo Vescovali.

(Giornale del Genio Civile, June, July, and August 1875, 80 pp., 6 pl.)

To determine the amount of water brought down by the Tiber in the flood of the 29th of December, 1870, as compared with that of the 24th of December, 1598, the following data have been collected in making plans for the improvement of the Tiber. The president of the Commission, Signor Possenti, proposed the formula of Professor Turazza, which gave 98,900 cubic feet per second for the flood of 1870, including 10,600 cubic feet per second estimated for the portion due to the inundated lands.

Professor Venturoli, by Eytelwein's formula, calculates the amount to have been 77,400 cubic feet per second, or about 21,200 cubic feet less than that calculated by Signor Possenti.

Observations taken during a flood in 1872, on a length of the river of 1,000 yards, between the bridge of S. Giovanni dei Fiorentini and the Ponte Sisto, and represented by a parabolic curve, showed the amount of water brought down, which being extended to represent the height of flood-water brought down in 1870, gave the amount of 84,800 cubic feet per second in the channel of the river, or only about 3,550 cubic feet per second less than the amount shown by Signor Possenti. To test this result still further, an equation, formed for an analagous problem on the Po, was applied to the data in hand, and proved the result to be correct. The total amount of water brought down in the flood of 1870 may therefore safely be taken to be 106,000 cubic feet per second. The section proposed in the plans for the improvement of the Tiber gives an available area for flood-water of 1,270 square yards, and a hydraulic mean depth of 28·5 feet; and omitting the resistance

caused by the bridges and bends in the river, and allowing for an average fall of 26·4 inches per mile, this section, by Eytelwein's and by Professor Turazza's formula, should carry 127,000 cubic feet of water per second, at a velocity of more than 6·5 feet, which amount may be increased by erecting a parapet wall along the top of the section.

On applying the hydraulic formula for finding the curve due to a stream of water to these data, it will be found necessary to lower the bed of the river, where it passes through the town, 7·5 feet, in order to combine the calculated depth of flood-water of 40 feet with the required level of the same 47 feet.

That the ancient bed of the Tiber was very much lower is proved by the level of the buildings in the Campo Marzio, and still more by the intrados to the Cloaca Maxima, which is now only about 3 feet above the ordinary water-level of the Tiber, whilst formerly a boat laden with hay is said to have been able to enter. The bridges also show that the bed of the river has risen considerably. In the case of the S. Angelo bridge, a pole driven into the bed of the river to a depth of 20 feet, meets with a hard obstacle, which seems to correspond with the stone platform shown in the ancient designs of this bridge, and if the river were cleared to this depth there would be ample space for the passage of flood-water equal to that brought down in 1870.

In 1598 the flood undoubtedly rose nearly 5 feet higher than in 1870, as is shown by ancient records; but the Author thinks that this was due to the many obstructions in the river at that time, and that the real amount was very little more.

By observations taken during eight years, Venturoli establishes the mean amount of water brought down by the Tiber to be 10,000 cubic feet per second, and takes the area of rainfall in the Tiber basin at 6,455 square miles, and the total depth of rainfall at 34·8 inches annually; but in order to apply the formula of Possenti, one-fifth of this must be deducted for loss by evaporation and otherwise, leaving an annual rainfall available for augmenting the Tiber of 27·3 inches.

The basin of the Tiber absorbs very little more than that of the Po, although apparently of a very absorbent nature. Observations show that the amount of water brought down by the Tiber in the flood of 1870, including that on the flooded lands, was, during the three days of the flood, 55,507 million cubic feet, of which 19,420 millions went to the sea through the channel of the Tiber, at a mean rate of 75,000 cubic feet per second, the rest remaining on the flooded land to diminish as the flood subsided. The total average flood of water in the valley of the Tiber was 213,900 cubic feet per second, or double the maximum amount able to be carried in its course, and triple of its mean.

The flood-water of the Tiber is calculated to be double that of the Po in relation to the area of its basin, which however is, in a great measure, due to the floods of the Tiber being produced by direct rainfall, whilst those of the Po are produced by the melting

of snow. Allowing for loss and absorption, the rain water that fell in the valley of the Tiber during the three days of the flood of 1870 must have been 83,260 million cubic feet of water, or 27,750 million cubic feet per day, which, if spread over a horizontal surface equal to the whole basin of the Tiber, would give a height of 1·85 inch, or about equal to the maximum registered at Civita Vecchia, Rome, and Perugia, thus confirming the opinion of Venturoli and Lombardini that the rainfall registered at Perugia may be considered equal to that of the whole basin of the Tiber. It is also noted that the flood did not reach its maximum until the third day after the heaviest rainfall.

Professor Venturoli has also proved, by an ingenious formula, that 2 inches of rainfall per twenty-four hours over the whole extent of the basin of the Tiber would be sufficient to have produced the flood of 1598. If the proposed works for the improvement of the channel were carried out, and the rainfall continued at the rate of 1·85 inch per twenty-four hours for more than three days, the height of the flood-water on the inundated lands would only be 26 inches in the first twenty-four hours, and in five days only 8·6 feet. In the town, it would reach the top of the slope of the proposed section only after the fifth day, bringing down 142,000 cubic feet of water per second; and if the course of the river were to be straightened and the bed lowered 1·6 foot, the discharge after the fifth day might reach 162,000 cubic feet without coming up to the top of the slope. The reasons for the flood of 1870 are stated to have been the abundant simultaneous rainfall over the whole of the basin of the Tiber, its long duration, and the fact of the soil being saturated with water, combined with the S.E. and S.W. winds, which are always dangerous at flood seasons in the basin of the Tiber, as the wind blowing contrary to the current of a stream seriously checks its velocity of discharge.

It may be assumed that no greater flood need be expected, and it will be sufficient to enlarge the channel to carry 106,000 cubic feet per second, which may be done by deepening it about 7·5 feet, from Ponte Milvio to below the railway bridge, enlarging its section, and giving the bed an inclination of about 7 inches per mile. The Author prefers the slopes of the proposed section to vertical walls, which, in case of rupture, would cause sudden and disastrous inundation. The excavation necessary for carrying out these plans would be about 1,300,000 cubic yards, at a cost of £48,000, which with £32,000 for the demolition of obstructions in the bed of the river within Rome, would make a total of £80,000. The Author then shows how by means of a deeper excavation of the bed of the river, and by straightening and thus shortening its course, the level of the flood-water may be further reduced by 5 feet.

These alterations would leave a channel for the ordinary discharge of the Tiber when not flooded capable of carrying 5,826 cubic feet per second with a depth of 8·2 feet, a sectional area

of 1937·5 square feet, and an hydraulic mean depth of 8·10 feet. There would be also a difference of level of 14·5 feet between the outfall of the Aniene and the level of the Tiber which might be utilised for irrigation purposes as well as for the town itself; for assuming the outfall of the Aniene to be 6,355 cubic feet per second, this would represent a power of 6,300 HP., which would be rendered useless only during twenty days in the year. The cost of these further improvements would be £60,000.

It is considered that even the expense of £60,000 to £80,000 would not be thrown away, as Rome would be freed from inundations, the flood basin and floods would be diminished, the industry and agriculture of Rome would be benefited, and the navigability of the river would be improved so as to admit vessels up to 500 tons burden.

J. K. R.

Report of the Commission on the Pollution of the Seine.

(Bulletin de la Société d'Encouragement, Sept. and Oct. 1875, 33 pp.)

The duties of the Commission included the investigation of the causes of the pollution of the Seine, and the selection of the measures best adapted to remedy the evil. After a careful inspection of the river near Paris, the following results were arrived at.

On the up-stream side of Paris, the aspect of the Seine is satisfactory, due in great measure to the recent drainage of the city. At certain points foul water is still discharged; but it is absorbed, and does not injure the fish. Below the bridge of Asnières, on the right bank, the main sewer of Clichy discharges an offensive stream loaded with refuse. Successive accumulations have formed a mudbank or shoal, which is only kept down by a costly process of dredging. Active fermentation creates large bubbles of gas upon the surface, some of which during the hot weather attained a diameter of between 3 and 5 feet. About four years ago, this pollution only extended to one of the three branches which the Seine forms at Clichy, but at present another branch is equally contaminated, and the right bank of the third is partially affected. No animal or vegetable life is to be found in the right branch. In the central, fish commence to appear, and are found more numerously in the left branch. Beyond the island of Clichy, and as far as that of St. Denis, the water retains its blackish colour, and the right bank is always coated with froth and greasy matter.

At St. Ouen, where the island St. Denis divides the river into two branches, the left is comparatively pure. The right branch, on the contrary, is the receptacle of the Clichy sewer, which follows the right bank. A little above the suspension bridge at St. Denis, this sewer discharges a black and fetid liquid with a powerful ammoniacal odour, covers the stream with froth, while gaseous exhalations extend to the isle of Epinay. The bed of the

river is covered with a black, fetid mud, full of those red worms found only in sewer water of the foulest character. This mud accumulates near the mouth of the sewer, and has to be removed by dredging. Between St. Denis and Epinay, the tributary the Croult contributes to the pollution.

An improvement takes place after the re-union of the two branches. The water, though still dark, is not so largely covered with floating refuse. The mud is considerably diminished, and fish reappear. Above the weir, at Beyons, in the left branch formed by the isle of Chiard, the odour becomes very strong, and the black mud at the bottom sometimes exceeds 2 feet in depth. At Marly, the sides of the lock are covered with a black, fetid deposit, and there are large quantities of scum and froth. The stream retains its dark colour equally in the right branch, which flows in front of Chatou. Beyond Marly, where the two arms re-unite, the colour diminishes, and at Meulan all external signs of pollution disappear.

The quantity of nitrogen in the water, before the Clichy sewer is discharged into them, is about 0·06 grain per gallon. This increases near Clichy to one-third, diminishes to one-sixth, and finally reaches nearly half a grain. Following the left branch, the quantity of nitrogen at Clichy amounts to about 0·105 grain per gallon. At St. Ouen an improvement takes place, and farther on, at St. Denis, the nitrogen diminishes to nearly 0·025 grain. Returning to the right branch, the stream is still contaminated at Epinay; and continues thus as far as Marly, where it amounts to about 0·25 grain per gallon. From Marly to Meulan the condition of the river improves, and at the latter locality the organic causes of fermentation have almost entirely disappeared. The quantity of oxygen varies from 1 grain in 200 gallons, to one-fifth of this quantity. The proportion is also very small as far as Marly. Between Maisons-Laffitte it has the same proportion as at Asnières, and from Meulan to Nantes reaches nearly double its original amount. In the left arm of the stream, formed by the isle of St. Denis, between St. Ouen and Argenteuil, the oxygen, like the nitrogen, manifests a sensible diminution opposite St. Ouen.

From the preceding facts, it is evident that between Clichy and St. Denis the water of the Seine into which the sewers drain, is unfit for domestic use, since it contains the elements of decomposition. Between Argenteuil and Marly, along the left arm, the river is less impure, and in a chemical point of view might be used for certain purposes with impunity. The aeration is however imperfect, and the stream is still charged with a large proportion of nitrogenised mineral substances. Beyond Marly, the water vastly improves. It is drinkable near Conflans, and in excellent condition at Meulan.

After analysing and experimenting with the mephitic gases emanating from the stream, the Commission arrived at the conclusion that there was no immediate danger to the public health.

The cause of the pollution of the Seine the Commission attributes to the influx into the river of the contents of the Parisian sewers. Twenty years ago the total length of the drains and sewers in Paris did not exceed 100 miles; at present they approach 500 miles, and convey the storm waters, and the whole of the house and street liquid drainage. The combined daily discharge of the sewers of Clichy and St. Denis into the Seine amounts to 57,200,000 gallons, each gallon of which contains 90 grains of solid matter. Thus in the course of one year about 130,000 tons of solid refuse are deposited in the bed of the river. The decomposition of the polluted waters is favoured by the sluggish nature of the stream. Owing to the erection of weirs at Suresnes and Beyons, the sewers of Paris discharge their contents into almost stagnant water.

It was decided that the continuation of dredging was imperatively necessary, to counteract the accumulation of shoals at the mouths of the sewers. Independently of the sanitary view of the question, the interests of navigation render the operations indispensable, particularly since the amount of solid deposit has increased 20 per cent. since 1868. Last year a sum of £72,000 was spent in keeping the mouths of the sewers open. The continuance of the dredging is not, however, to be regarded as effecting any solution of the difficulty.

Among the propositions for purifying the Seine, the prolongation of the sewers as far as its mouth, meets with the objections that the expense would be enormous, and that the cause of pollution would be simply removed to some other part of the shore. Another method, consisting in the extension of the sewers to the confluence of the Seine and Oise, would merely spread the evil, without in any manner destroying the active cause, namely, the putrescible ingredients. It has also been proposed to dilute the contents of the sewers, either at the outlet or at some other point, with a large quantity of fresh water. This simple dilution is open to the same objections: it would enlarge the sphere of infection, and would not permit of the utilisation of any of the fertilising ingredients of the sewage for agriculture. The filtration scheme was repudiated by the Commission, on the grounds that the result is never complete. Moreover, the working operations are very expensive, and the existence of filter beds constitutes a serious danger to the public health. The same remarks apply to the decantation method, or filtration by simple gravity.

For some time past, experiments have been carried out on the plains of Gennevilliers, respecting the purification of liquid sewage by the aid of chemical reagents, notably of sulphate of aluminum. A clarified effluent water is undoubtedly discharged from the reservoirs, but it is a serious mistake to confound an effluent thus prepared, with one really purified and free from all elements of pollution. Sulphate of aluminum, after its decomposition by the alkaline contents of the sewage, and having thrown down the alumina in a gelatinous condition, effects the simple mechanical

result of a flux. The solid ingredients are drawn to the bottom of the filters, while the dissolved and putrescible ingredients remain in the so-called purified water. Chemical analysis has abundantly proved that this effluent retains two-thirds of the total nitrogen in the original liquid, and one-third of the organic ingredients is therefore unfit for domestic use, and when introduced into a stream, cannot fail to pollute it in some degree. The application of the process on an extensive scale would deposit in the reservoirs enormous masses, of but small agricultural value, averaging about 5*s.* per ton, while the cost of the chemicals alone would amount to more. Taking into consideration other items of outlay, such as working expenses, carriage, and site, financial reasons alone render any of these processes hopeless in all cases of any magnitude, and the Commission was unanimous in rejecting all plans to purify the sewage by chemical reagents. It is in the combined action of the soil and vegetation that they appear to have found the remedy. In applying it to irrigation, sewage is rendered not only innocuous, but fertilising and productive.

The irrigation on the plains of Gennevilliers is both salubrious and economical. When submitted to chemical analysis, the effluent water was found to be perfectly free from all putrescible ingredients, and, in fact, purer than the water taken from the Seine, above the point where the sewers discharge their contents, and purer also than the water of wells in the same district. The soil, aided by the assimilating powers of the plants, absorbs and deodorises all the noxious properties of the sewage, so as to prevent all chance of infection to the surrounding district. The springing up of an entirely new village, and the increase of building in the immediate neighbourhood of the irrigated territory, are guarantees that public health is not endangered. The quantity, quality, and size of all the vegetables, fruits and flowers grown upon the farm, sufficiently indicate the great value of the system in an agricultural sense. The results, obtained at Gennevilliers, have convinced the Commission, that the remedy lies in the utilisation of the sewage of Paris by irrigation; that this can be done without danger to the health of the neighbourhood, to the benefit of agriculture, and in accordance with the great natural law of restitution and reproduction.

T. C.

On the Dredging of the Roadstead of Port Said.

By F. DE LESSEPS.

(Comptes-rendus de l'Académie des Sciences, 4th October, 1875, pp. 546–549.)

Dredging operations were undertaken in the open roadstead of Port Said, in 1873 and 1874, for the purpose of removing the deposits formed in the eddying water at the head of the jetties; and though the dredged channel was partially refilled during the

winter storms, the depth of the adjacent area was increased. The west jetty was also extended, so that the maintenance of the depth necessary for the navigable channel might be insured. The incessant surf on the jetties during their construction, from 1866 to January 1869, had scoured the bottom; but subsequently a bank of sand having formed along the inner side of the jetty, and the currents being checked by this and also by a temporary bank formed outside by the material thrown out of the dredge-boats, the depth of water at the entrance began to decrease. From September 1873 to the end of 1874, 331,200 cubic yards of deposit have been dredged from the roadstead, and 295,000 cubic yards from the bank on the east side of the jetty, and the jetty has been extended about 1,640 feet. In July 1874 the 5-fathom line had come 820 feet nearer the shore in front of the end of the jetty; and from soundings taken last July, it appears that the improvement has continued, and that the 5-fathom line forms a sort of bay at the entrance of the channel about $\frac{3}{8}$ mile in width. The extension of the jetty has consequently been stopped since November 1874, but the dredging outside is being continued. The dredger, which has been working for three years in the sandy, clayey, and occasionally very compact deposit, has dredged, on an average, whilst in full work under shelter, 240 cubic yards per hour, and in the open roadstead 132 cubic yards per hour. Waves exceeding 2·3 feet do not prevent the dredging operations.

L. V. H.

The Port of Venice. By Professor G. Zanon.

(Rivista Marittima, October 1875, pp. 59–141, pl. I. and II.)

The first portion of this article gives a descriptive and historical account of the Maritime Arsenal or Dockyard of Venice, from its origin in 1104 till now, principally extracted from a work, "Venezia e le sue Lagune," 1847. The greater portion of the article is, however, taken up with the more important points that affect the proposed improvement of the passage from the Dockyard to the sea, about $3\frac{3}{4}$ miles in length, consisting of the Canal delle Marani and the Porto di San Nicolo del Lido, now impassable for large vessels, for want of depth, and from the existence of a sandbar at the mouth.

The Venetian lagoon is separated from the sea by a narrow strip of coast through which a number of channels, 'porti,' or 'porto canali,' admit the tidal water in ebb and flow, the ebb lasting only one-sixth of the time of the flow, and thus giving greater scouring power and velocity. The deep-water passages with which these debouch towards the mouth are technically known as 'foci,' and the intervening strips of shore as 'litorale,' or 'lidi.' The three principal foci of Venice, those of Treporti, San Erasmo,

and San Nicolo, uniting in one mouth, with a breadth of about 3,600 yards, have been much altered and blocked by shoaling and sandbars for centuries past. The causes of this deterioration have been attributed to various actions of the tides, currents, and winds, by Cialdi, Sabbadini, Bressan, Zendrini, and others. The shoaling of the Foce San Nicolo, however, is due also to special local causes. The Foce San Erasmo directs its waters at right angles to it; and the silting at the junction has steadily increased from this cause, forming an important shoal, and rendering it almost unnavigable. As the Foce San Nicolo leads to the Porti San Nicolo and delle Marani, and through them to the dockyard, its improvement forms the most important part of any design for the Port of Venice.

As regards tidal action, the rise of ordinary spring and neap tides does not exceed 2·8 feet, though when aided by the sirocco, or south-east wind, it is much greater, and when counteracted by a north wind amounts to only 13·8 inches. The mean rise is 22 inches, and the extreme in 1867 was 4·3 feet. These extremely high tides are beneficial, as they fill the lagoons, extend over the maremme, or marshes, and clear away accumulations and unwholesome soil. The strong ebb also has a powerful scouring action in the main channels, porti and foci, giving greater depth and favouring the operation of a greater volume of discharge. It has a prejudicial effect, however, on the artificial canals parallel to the shore, as it causes silting in them, and necessitates dredging.

It is, therefore, from a consideration of the natural conditions most favourable to the improvement of the porti and foci that the best artificial means of attaining the same object may be deduced. The larger the quantity of water that can be retained in the lagoon, the greater will be the scour in the channels, and their consequent improvement. Hence a certain advantage might be obtained by diverting neighbouring rivers into the lagoon, as was done in the case of the river Brenta and the lagoon of Chioggia; but as the extension of the Venetian lagoon much beyond its present area would be a serious detriment to the neighbourhood, this would involve retaining it within its present limits by embankments, which, though costly, would be also a means of permanently reclaiming for cultivation a large tract of marsh land.

In 1349, the first attempt to improve the Canal delli Marani and Porto San Nicolo, then discovered to be deteriorating, consisted in entirely blocking up the mouth of the Porto di San Erasmo and thus forcing its waters through the former passages; but as this caused damage to the buildings on the islands of S. Pietro and delle Vergine, the passage was hence opened again. In 1360 a spur, the Garzina, was thrown out from near S. Andrea, in order to narrow the mouth of the Porto S. Erasmo. The result was some damage to the opposite bank at the Fort San Nicolo, to mitigate which a protective embankment and spur parallel to the former, called the Molo Guardiano, was made at the Punta di S. Nicolo. These spurs were afterwards strengthened, shortened, and length-

ened at various times without producing any very satisfactory result. In 1474, the condition of the Porto S. Nicolo became so bad that it was entirely deserted by large vessels, which were compelled to go to the neighbouring port of Malamocco. From that time until 1723, when some additional spurs were taken in hand, various engineers drew up projects of improvement, none of which were completely carried out, although some were commenced. In 1727 another difficulty presented itself: the water had cut a new passage from the Canal delle Marani, between S. Pietro and S. Elèna, to the Canal de S. Marco, the results being a diminution of water in the S. Piètro mouth of the Canal delle Marani, and damage caused by the reflex action of the remaining water to the Castle of S. Andrea, in the first place, and to the Punta S. Nicolo on the opposite shore afterwards. From that time until the union of Venice with Italy in 1866, the Porto S. Nicolo remained in a deteriorated condition, partly compensated for by the improvement of the port of Malamocco, which was used by all large craft.

In 1866 a commission took charge of the proposed improvement of the Porto S. Nicolo, but only with the view to rendering it available for coasting vessels. Plans were brought forward by Scotini, Contin, and Müller, and by Mati, who modified the project of Contin. This Mati-Contin project received the approval of the Giunta Lagunare in 1871, and may yet be executed. It is far more extensive than any of the preceding, involving larger works. It does not, however, interfere with, or attempt to regulate any of the porti or foci separately, but simply improves the mouth, or combination of the three foci, by confining the exit and entrance of the tidal water from the estuary within two long sea-walls extending into deep water, and by narrowing the entrance from 3,600 to 1,090 yards. The axis of the trumpet-curved passage thus formed is directed towards the south-east, or against the sirocco. The flanks of the sea-walls rest on the Punta dei Sabbioni, on the north, and the Punta S. Nicolo on the south side, the former wall being 3,762 yards, the latter 2,985 yards in length, their type of construction generally following that adopted at Malamocco, although artificial blocks of 13 cubic yards each will be used instead of quarried stone. Their cost is estimated at £228,000, the latter expedient having diminished the estimate by one-third.

Professor Zanon enters into a lengthy critical examination of this Mati-Contin project, and records the following grave objections to it:—

While these sea-walls are so designed as to retain the existing quantity of water in the lagoons, to scour away the principal sandbar of the Foce di S. Nicolo, to deepen it at its outer extremity, and to admit vessels of large draught within the sea-walls, the design may fail in the most important object of giving sufficient depth to allow large vessels of war reaching the dockyard. The porti and foci remaining severally unregulated, there is every

reason to believe that in the vast expanse between the Punti Sabbioni and S. Nicolo large shoals will continue to be deposited.

Some additional embankments would still appear necessary at the entrance of the Porto Treporti, in order to control its waters until they unite with those of the other two porti.

The improvement of the Porto S. Nicolo involves the abandonment of the existing Port of Malamocco, which communicates with Venice by means of a ship-canal about 6·2 miles in length, or rather its conversion into a simple harbour of refuge, as the communicating canal could not be kept up under the altered conditions; the probable result of the execution of the Mati-Contin project being that vessels would eventually be prevented from reaching Venice by either course.

The author, therefore, proposes modifying this project by making an aditional sea-wall 3,280 yards long, commencing at the Castle of S. Andrea, and running parallel to, and at a distance of about 500 yards from the southern sea-wall before mentioned. This would cost about £120,000, remove the above objections, and provide a communication from the castle to an armoured fort in deep water, which would protect the entrance of the harbour. It would give a deep-water passage up to the dockyard, probably of no less than 56 feet throughout, and allow large ironclads to enter the docks. The course would also be kept clear of any silting due to the action of the waters of the Porti S. Erasmo and Treporti, without necessitating either a fourth sea-wall for the latter canal mouth, or the employment of the water of the former, which, being supplied by a lagoon much smaller than that of the Porto S. Nicolo, is comparatively valueless.

L. J.

The Port of Aveiro. By S. A. P. da Silva.

(Revista de Obras Publicas e Minas, April, May, and June 1875, 76 pp.)

The production of salt, by the evaporation of sea water, has been the chief industry of the Aveiro district from remote ages. The town, of the same name, about 5 miles from the coast, is surrounded by an extensive area of land, laid out into drying pans, and prepared for the reception and evaporation of salt water. The port itself is formed by several small rivers, such as the Oiro, Espinho, Villa, and Mira, uniting within a short distance from the coast, which there develop into a series of extensive lagoons, protected from the Atlantic by sandbanks. As these are, however, exposed to the full wash of the ocean, and to the prevalent north-west winds, the sand is kept in constant motion, causing frequent alterations in the position of the entrance to the

port, and the formation therein of shoals, greatly to the prejudice of navigation.

The first important changes are recorded about 1656, and a century afterwards silting had so reduced the entrances, that the river water was backed up, the lower portion of the town flooded, and the production of salt, for the time, seriously interrupted; however, one or two unusually rainy seasons followed and scoured out the channels by floods.

The Paper describes at some length the earlier attempts to improve the tidal channel and maintain it free from obstructions, but they appear, in most instances, to have been only temporarily successful.

The Author in 1858 on taking charge of the works for improving the port, found that a spit of sand had been gradually forming across the old entrance, causing the channel to flow in a direction parallel to the coast, and to come out 1,050 yards to the south. To remove this obstruction he decided to reconstruct and extend a mole, which had been made across the lagoon during the early part of the present century, in continuation of an embankment from near Aveiro; this he intended should act as a guide to the waters in the channel. Some years previously a portion of the old mole, 324 yards in length, had been undermined and washed away by the stream. It was anticipated that the mole, being placed at right angles to the spit, would cause the stream to impinge against the sand and gradually cut out a new channel. This work was carried out during the months of July and August 1859, and when completed proved entirely successful, for in the place of an extensive sandbank above the level of high water, a channel was formed, which had attained, on the 13th of December, a depth of 13 feet below the level of low water, and of 15·75 feet on the 8th of February of the following year, when further soundings were taken.

The Author's attention was next drawn to the advisability of increasing the flow of water through the new channel, and regulating the currents within the port. To effect this he determined to close the Vagueira opening, between the lagoon and the ocean, situated about 5½ miles south of the port entrance, through which the water of the Mira river escaped. He had observed that the high tide, of the waters flowing from Mira, took place at Cambia (an opening in the embankment from Aveiro) about two hours later than at the new channel, in consequence of the difference in distance. He concluded that by placing a series of self-acting sluice-gates at Cambia, opening outwards towards the north, the scouring action of the water at Vagueira would be so reduced during the ebb tide, as in course of time to silt up and close that opening. The work as executed consisted of eighteen sluice-gate openings, each 13 feet wide, with intermediate piers of rubble masonry 3·28 feet thick, and carrying a superstructure, which formed a bridge, 16 feet in width and 302 feet in length. Each sluice-gate had two wooden doors hinged

to the sides of the piers, and meeting at an angle in the centre, allowing them only to open when the stream set in from the south. The foundations consisted of loose stones bound together with fascine work, and the sill was placed a little below the level of the lowest tides. When the work was completed, in March 1863, the Vagueira entrance showed a depth of over 13 feet of water; but so soon as the sluices began to act, this depth rapidly decreased, and by August of the same year the opening had closed up completely, and has remained so ever since. The sluice-gates being no longer required were then removed. It appears that considerable benefit has been derived from the additional water of the Mira affluent, having to pass through the new channel.

The Author proceeds to recommend, and describe in detail, various works which, if carried out, would further improve the port. Amongst these are: an extension of the mole, to counteract the movement of the drifting sands which have lately been accumulating at the bar; the opening out of various new cuts and channels, so as to shorten the distance from Aveiro to the sea and give a better direction to the waters coming from the Espinheiro canal; the removal of some of the old groynes, and the erection of others to improve the coast line; and the planting of pine trees over the whole expanse of sands on this coast, estimated to contain 7,637 statute acres, at present exposed to the free action of the wind. He strongly recommends plantation as a simple means of arresting the drifting sands, and suggests that, by forming temporary shelters, a nucleus might easily be formed from whence the plantation could afterwards be gradually extended on all sides. The total estimated cost of these works is £61,500.

G. Kn.

Steam Boilers. By P. Havrez.

(*Second Abstract.*)

(Annuaire de l'Ass. des Ing. Sortis de l'École de Liége, July and August 1875, pp. 83–151.)

It was stated in the first abstract,[1] that the boilers which formed the subjects of investigation were classed under four types:—the French boiler, the Cornish boiler, the Lancashire boiler, and multitubular boilers. The French boiler was the subject of the first article by M. Havrez, the remaining three kinds are now considered. Finally, the respective volumes of the water-room and the steam-room in the four types of boilers are dealt with.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlii., p. 322.

The following symbols are used :—

D = diameter of the boiler, in inches.
d = diameter of the flues, or internal fireplaces, in inches.
L = length of the shell of the boiler, in feet.
l = length of the fire-grate, in inches.
N = nominal HP., reckoned at the rate of 16·9 square feet per HP.
n = the effective pressure in atmospheres.
P = the total weight of the boiler, in lbs.

II. Cornish Boilers.

The relative diameters of the shell and the flue are regulated by the requirements for internal clearance and space as follows :—

	Inches.
Between the under side of the flue and the shell . . .	4 to 6
Depth of water over the flue	4 „ 8
	8 „ 14

making, with allowance for the thickness of plates of the flue, a constant difference equal to, say, from 12 to 16 inches. The steam-space is from a fifth to a third of the diameter. From these data,

$$D - d = (12 \text{ to } 16) + \frac{D}{5 \text{ to } 3},$$

and by reduction, $$D = (1 \cdot 5 \text{ to } 1 \cdot 25)\, d + (15 \text{ to } 24),$$

D and *d* being expressed in inches. The mean value for D, the diameter of the shell, in terms of *d*, the diameter of the flue, is

$$D = (1 \cdot 4\, d + 14) \text{ inches.}$$

The alternative formula is given,

$$D = 1 \cdot 7\, d.$$

To give a proper sectional area for the air and smoke to pass away, the relations of the diameters of the shell and the fire-flue to N, the nominal HP., vary as the square root of the HP. The flue is divided by the grate into halves, and the section of the lower half, or ashpit, should be equal to that of the chimney, which is at the rate of 15·5 square inches, or 1 square decimètre, per HP. Thus

$$\frac{0 \cdot 7854\, d^2}{2} = 15 \cdot 5\, N; \text{ whence } d = 6 \cdot 32 \sqrt{N}.$$

To allow, however, for the contraction of thoroughfare over the

bridge 2 inches are added to the diameter, and for 25 HP.—assumed as being in practice the medium value of N—

$$d = 6 \cdot 72 \sqrt{N}.$$

As $D = 1 \cdot 7\, d$, then, by substitution and reduction the following mean value for D is finally adopted:—

$$D = 24 + \sqrt{N}.$$

The length of the furnace also varies as the square root of the HP., but the width of the fuel in combustion is practically reduced by 2 inches, by reason of the cooling action of the water at the sides; and allowing 77·5 square inches, or 5 square decimètres, of grate-area per HP., the area is

$$l\,(d - 2) = 77 \cdot 5\ N;\ \text{or, at least, } ld = 77 \cdot 5\ N,$$

in which l = the length in inches. By substitution and reduction, the following mean value is arrived at:—

$$l = 11 \cdot 8 \sqrt{N},$$

which is not much less than twice the diameter of the flue.

The length of the boiler varies as the square root of the HP. Taking two-thirds of the circumference of the flue (the lower half being covered with ashes), and the lower half the shell, as heating surface; and allowing 16·9 square feet, or 157 square decimètres ($= 50\,\pi$) per HP., though boiler-makers allow at the most 14 square feet, or 130 square decimètres; the value of L, the length, in feet, is

$$L = 5 \cdot 1 \sqrt{N}.$$

The length is a little over five times the diameter of the shell; and is a little over five times the square root of the HP.

The weight of the boiler is proportional to the HP.; and the weight per HP. is proportional to the pressure, and to the square root of the HP.

This conclusion is arrived at in terms of the unit of weight: 10 kilogrammes per cubic decimètre, or 624 lbs. per cubic foot, to allow laps and rivets, &c. (see page 323, vol. xlii.); and of the regulated thickness of the plates (see page 325, vol. xlii.); which is, for the shell plates $(2 + 1 \cdot 5\, n\, D)$ millimètres; and for the flue plates $(3 + 1 \cdot 8\, n\, d)$ millimètres; D and d being expressed in mètres. In round numbers, the weight in pounds per HP. is found to be as follows:—

$$\frac{P}{N} = 110 + 22\, n \sqrt{N}.$$

The following table contains the particulars of Cornish boilers, from 9 HP. to 56 HP., which are the lowest and highest limits of power, in practice, for with a power less than 9 HP., the tube would

only have a diameter of 19·5 inches (5 decimètres), while with a power above 56 HP., the grate would exceed 7·4 feet in length.

CORNISH BOILERS.—TABLE of POWER and DIMENSIONS of BOILERS from 9 HP. to 56 HP.:—the PRACTICAL LIMITS of POWER for a SINGLE INSIDE FLUE.

1. Nominal HP. . . . . N.	9	12·25	16	20·25
2. Square root of nominal HP. . $\sqrt{N}$.	3	3·5	4	4·5
3. Length of grate, inches . . . . $11 \cdot 8\sqrt{N} = D = l$.	35·4	41·3	47·2	53·1
4. Diameter of the boiler, inches . . $D = 24 + 8\sqrt{N}$.	48	52	56	60
5. Length of the boiler, feet, $5 \cdot 1\sqrt{N}$.	15·3	17·9	20·4	23·0
6. Diameter of the flue, inches, sensibly $d = \frac{l+4}{2}$.	19·7	22·6	25·6	28·6
7. Do. do. do. do. $d = 2 + 6 \cdot 32\sqrt{N}$.	21	24·1	27·3	30·4
8. Weight per HP., pounds . . . . $\frac{P}{N} - 110 = 22\,n\sqrt{N}$.	66 n	77 n	88 n	99 n
9. Weight per HP., pounds, when $n = 4$ atmospheres effective, 5 atmospheres absolute	374	418	462	506
10. Total weight of the boiler for $n = 4$ pounds.	3,366	5,120	7,392	10,247
11. Do do. do. do. tons.	1·50	3·29	3·30	4·58

Reference.	*Continued.*						
1. HP. .	25	30·25	36	40	49	50	56·25
2. $\sqrt{HP}$.	5	5·5	6	6·33	7	7·07	7·5
3. Inches	59·0	64·9	70·8	74·4	82·6	83·4	88·5
4. Inches	64	68	72	75	80	80·6	84
5. Feet .	25·5	28·1	30·6	32·3	35·7	36·1	38·3
6. Inches	31·5	34·5	37·4	39·2	43·3	43·7	46·2
7. Inches	33·6	36·8	40·0	42·0	46·2	46·7	49·4
8. Pounds	110 n	121 n	132 n	139 n	154 n	155·5 n	165 n
9. Pounds	550	594	638	666	726	732	770
10. Pounds	13,750	17,968	22,968	26,640	35,574	36,600	43,312
11. Tons .	6·14	8·02	10·25	11·90	15·90	16·34	19·33

III. LANCASHIRE BOILERS.

The dimensions and proportions of the double-flue or Lancashire boiler are regulated by considerations analogous to those which applied to the Cornish boiler.

The Lancashire boiler should not be employed for less than 25 HP., for which the appropriate width of flue would be only 24 inches; nor for more than 64 HP., which leads to excessive dimensions. The practical limits of power are from 30 HP. to 60 HP.

The diameter of the shell should exceed by 16 inches twice the diameter of the flues to afford sufficient clearance; or, in inches,

$$D = 2\,d + 16;\ \text{and}\ d = 0{\cdot}5\,D - 8.$$

As mean equivalent expressions the following are preferred:—

$$D = 2{\cdot}5\,d;\ \text{and}\ d = 0{\cdot}4\,D.$$

The sectional area of the chimney, 15·5 square inches per HP., should be equal to that of two half flue-tubes, or of one whole tube. Then

$$0{\cdot}7854\,d^2 = 15{\cdot}5\,N;\ \text{whence as a minimum,}\ d = 4{\cdot}44\,\sqrt{N}.$$

Adding 2 inches to provide sufficient passage-way over the bridge,

$$d\,(\text{in inches}) = 2 + 4{\cdot}44\,\sqrt{N}.$$

Substituting these values of d, in the above value of D, namely, $D = 2{\cdot}5\,d$, and reducing,

$$D = 11{\cdot}4\,\sqrt{N}.$$

The length of the grate should increase as the square root of the HP., when the grate-area increases with the power. Allowing 5 square decimètres, or 77·5 square inches, of grate per HP., and the total area of grate being $l \times 2\,d$,

$$77{\cdot}5\,N = l \times 2\,d,$$

whence, by substitution and reduction, $l = 8{\cdot}65\,\sqrt{N}$.

The sum of the width of the two grates is practically equal to their length. The width of each grate, or the diameter of the flue, minus 2 inches as ineffective margins, increases uniformly by 4·44 inches, when the power is augmented in the order of the odd numbers, 3, 5, 7, 9, &c., HP. This corresponds to an average augmentation of 0·314 inch per HP. added, between 30 and 60 HP. Similarly, the length of the grate is increased by 8·65 inches in the same order, being an average augmentation of 0·63 inch per HP.

The length of the boiler should increase in the ratio of the square root of the HP., to provide heating surface in the ratio of the power. Allowing two-thirds of the circumference of the flues, and half that of the shell, as heating surface, the simple expression

$$L = 14{\cdot}4 + 0{\cdot}46\,N$$

is recommended as sufficiently exact; here, the length increases at the rate of 0·46 foot, or 5·5 inches per HP.

The total weight should be proportional to the power, and the weight per HP. is in the ratio of the pressure, and of the square

root of the power; according to the following formula for the weight per HP. in pounds:—

$$\frac{P}{N} = 220 + 12 \cdot 35\, n \sqrt{N}.$$

The following are the weights of boilers for several powers, and for 5 atmospheres of pressures, calculated by this formula, together with those of boilers as actually manufactured, for comparison:—

	Weight by Formula.	By M. Piedbœuf.	By M. Pétry-Chaudoir.	
HP.	lbs.	lbs.	lbs.	kilog.
30	16,764	22,000	19,845	(9,000)
40	24,420	29,370	26,460	(12,000)
50	32,780	34,540	33,075	(15,000)
60	41,800	41,360	39,690	(18,000)

IV. Multitubular Boilers, Portable Engines, Locomotives.

Multitubular boilers may have two fire-tubes or a fire-box.

Let D and L be the diameter and length of the boiler.

d and l the diameter and length of the fire-tubes.

n, δ, and λ the number, diameter, and length of the flue-tubes.

σ the sectional area of the flue-tubes per HP.

The Author lays down three propositions:—

1st. That the length of the flue-tubes is independent of the HP., with any system of furnace.

2nd. That the length is proportional to the diameter of the flue-tubes, and to the heating surface per HP.; and is in the inverse ratio of their sectional area per HP.[1]

3rd. That the nominal HP. is proportional to the number of tubes; the number of tubes being in the inverse ratio of the square of their diameter.

It is added that the power supplied by each tube is five or six times as much, and the fire is five times as active, with a forced draft as with an ordinary draft.

These propositions follow from the rule that the total section of the flue-tubes should increase in the ratio of the power.

The direct heating surface, whether fire-box or fire-tube, is generally a tenth of the total heating surface; and, allowing 1·5 square mètre, or 16·1 square feet, per HP., the length of the tubes is

$$\lambda = a\, 16 \cdot 1 \frac{N}{n \pi \delta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (a)$$

in which a is the fraction of tube-surface $(\frac{9}{10})$. The total sectional area is, in square inches ($15\frac{1}{2}$ to 23) N; equivalent to from 1 to 1·5 square decimètre per HP.

Again, $$n \pi \frac{\delta^2}{4} = (15 \cdot 5 \text{ to } 23)\ N,$$

whence $n = A \frac{N}{\delta^2}$, which supports the third of the above propositions. By reduction and substitution in equation (a), $\lambda = \frac{a \Sigma \delta}{4 \sigma}$, which supports the first and second propositions.

For the fraction $a = \frac{9}{10}$, and a section, for very hot air, equal to the maximum, 23 square inches (1·5 square decimètre) per HP. required by the contraction of the fluid veins,

$$\lambda = \frac{0 \cdot 9 \times (16 \cdot 1 \times 144) \text{ square inches}}{4 \times 23 \text{ square inches}} \delta = 22 \cdot 5\ \delta;$$

that is to say, the length is equal to 22·5 times the diameter.

When the section is only $15\frac{1}{2}$ square inches (1 square decimètre) per HP., with a stronger draft, the length is 33·25 diameters.

If the heating surface be increased to 32·2 square feet, or 2 square mètres, per HP.; whilst the sectional area remains at $15\frac{1}{2}$ square inches per HP., the draft is to be further augmented, and the length is 45 diameters.

In locomotives, in which the draft and the combustion are five or six times more active, and in which there are about 8 square feet, or 75 square decimètres, per HP., a section of only a sixth is required; then,

$$\lambda = \frac{0 \cdot 9 \times (8 \times 144)}{4 \times 15 \cdot 5 \times \frac{1}{6}} \delta = 100\ \delta,$$

giving a length equal to 100 diameters. If the heating surface is two-thirds of the above, or 5·38 square feet (50 square decimètres) per HP., the length is 66 diameters.

The above deductions for the proportion of the length to the diameter of the flue-tubes are supported by various practical examples adduced by the Author.

Relation of the HP. of locomotives to their dimensions.—The heating surface of stationary boilers is only from twenty to thirty times the grate-area; whilst it is sixty times the grate-area in locomotives. Again, the locomotive, in some experiments made by the Author, evaporated 6·15 lbs. of water per square foot of surface with coke, and 8·8 lbs. with briquettes; being from one and a half to twice the rate of evaporation in stationary boilers. Thus, for the same area of grate in the furnace, the combustion and the evaporation are from four to six times more rapid in the locomotive than in stationary boilers; and the power of locomotives is equivalent to 1 HP. per square decimètre, or $9\frac{1}{4}$ HP. per square foot, of grate-area; and to more that 2 HP. per square mètre, or about $\frac{1}{5}$ HP. per square foot of heating surface.

In locomotive-boilers having tubes of $1\frac{3}{4}$ inch in diameter

and 12 feet long, and in which the heating surface is sixty times the grate-area, each tube represents 1 HP.

There follows here a discussion of the diameters of flue-tubes suited for different classes of boilers.

The Author next shows that the diameter of shell of a multitubular stationary boiler, calculated so as to be fitted either with one fire-tube, as in the Cornish boiler, or with two fire-tubes, as in the Lancashire boiler, is sufficient to contain in its lower half a faggot of 3-inch tubes, having the same total sectional area as the half of the fire-tubes.

V. Water-space and Steam-space in Boilers.

The ratio of the water-space and steam-space of boilers to the heating surface, and consequently to the HP., is special, and is sensibly constant for each type of boiler.

The total capacities for water and steam, per square mètre and per square foot, of the different types are as follows:—

Boiler.	Capacity per Square Mètre of Heating Surface. Litres.	Capacity per Square Foot of Heating Surface. Cubic Foot.
1. Simple boiler	500	1·63
2. Boiler with two heaters	300	0·98
3. Lancashire boiler	250	0·82
4. Main multitubular boiler	150 to 100	0·49 to 0·33
5. Portable engine boiler	80	0·26
6. Locomotive boiler	55	0·18

The ratio of the steam-space to the water-space, putting the total capacity of the boiler = 100, varies from 15 : 85 to 40 : 60.

For locomotives, the ratio is	as 33 : 67
For marine multitubular boilers	„ 48 : 52
For Cornish boilers	„ 43 : 57

This and the preceding sections of the Paper contain numerous examples from current practice in support of the deductions of the Author.

Here ends the first part of the investigation, respecting the relative dimensions of boilers of various types. The second part treats of the economical performance of boilers and their furnaces. The third part contains a graphical investigation applicable to the formulæ of boilers and practical mechanics.

In the second part of his investigations, M. Havrez discusses the economic conditions to be fulfilled by boilers and their furnaces; and the form of boiler finally adopted by him and his brother, the results of many years' experience and investigation, is that of the *chaudières accolées*, or the united boilers. These consist of three boilers, placed in a semicircle over the grate—one on each side of the grate, the others over the centre, connected by neckings. The

interspaces between the boiler, from 4 to 6 inches wide, are occupied by firebrick partitions, and thus practically a semicircular arch is so constructed above the grate, as to derive the maximum benefit from the radiant heat of the fire. The fuel is not permitted to touch any metallic surface; the sides of the furnace are therefore constructed of firebrick, and they support the lateral boilers, one at each side. The flaming products of combustion pass along the archway to the far end of the boilers, and return by a flue outside one of the lateral boilers; thence, traversing under the ashpit, rising and repassing outside the other lateral boiler to the chimney at the far end.

M. Havrez quotes the results of experiments made by M. Burnat, on the evaporative efficiency of Ronchamp coal in a common boiler, in which the grate was placed at various levels below the boiler. Eight different levels were tried for a week at a time, and the following were the respective quantities of water evaporated per pound of fuel:—

Grate below boiler . .	12,	14,	16,	18,	20,	22,	24,	26 inches.
Water per lb. of coal .	7·93,	8·06,	8·04,	8·10,	8·15,	8·25,	8·12,	7·99 lbs.

showing that from 20 to 22 inches clear height was the most economical level; and M. Havrez argues that if a space of ½ mètre between the boiler and the fuel is necessary for effecting the greatest efficiency, the distance zero must be extremely disadvantageous. Hence his objection to internal fire flues.

Developing the proportions of his boilers, M. Havrez exemplifies them for boilers of 15, 30, and 50 HP. The heating surfaces, at the rate of 1·5 mètre or 16·1 square feet per HP., are respectively 241·5, 483, 805 square feet. The diameters of the superior boilers are respectively 34, 40, and 48 inches; and of the lateral boilers, or heaters, 21, 24, and 28 inches. The grate is, in each example, 32 inches above the level of the ground for facility of stoking. The grate should be as nearly square as possible; for the more nearly square it is, the more intense is the heat in the middle, and the greater is the proportion of heat radiated. The three grates are, then, 32 inches, 48 inches, and 60 inches square, yielding an area at the rate of 0·48 square foot per HP. For small powers, however, a little extra allowance of grate is recommended, say 0·54 square foot per HP. For high powers, on the contrary, 0·43 square foot is sufficient. The clear height above the bridge is taken at a third of the length of the grate.

With these proportions, M. Havrez claims for the "united boiler" an evaporative efficiency one-third greater than that of the French boiler. His experiments show the following evaporative efficiencies:—

	In ordinary work.	By careful experiment.
Ordinary French boiler . . .	6·1 to 6·5 lbs.	8·1 lbs.
United boiler	8·5 lbs.	10·5 lbs.

The fire-bars of the kind called knife-blades are not more than

0·6 inch thick, with 0·2 inch air-spaces. These proportions have been adopted, after many trials, as the most advantageous, causing the thin layers of air to be heated before entering the fire, and keeping the bars cool and free from clinker.

The evaporative performances are as follows:—

	Water evaporated per lb. of coal.
Consuming from 14 to 16 lbs. of coal per square foot of grate per hour.	10·8 lbs.
" 25 " 27 " " "	8·0 "
" 34 " 36 " " "	7·0 "

The Author gives in detail the results of numerous experiments with the "united boiler;" and he concludes that, from every point of view, the best system of boiler is that which affords a spacious furnace, and a large and very long central flue surrounded by boilers and heaters connected in the usual manner.

In an appendix, M. Havrez makes a long communication on the use of cast steel in the construction of boilers; and another on the thickness of boilers made of iron and of steel, and on riveting.

D. K. C.

Report on Comparative Trials of an Elephant Boiler, and of two Boilers internally fired.

(Bulletin de la Société Industrielle de Mulhouse, June 1875, pp. 241–272.)

It was resolved, in 1874, to make exhaustive trials of the two types of boilers, the Lancashire and the elephant, under the same conditions. They were to have the same grate-area, and the same heating surface; to consume the same quantity of the same coal with the same draught, with the same stoker. The temperatures of the gases in the chimney were to be observed, and also the quantities of priming water drawn over by the steam. A third boiler was added, on the "Fairbairn" system.

The Lancashire boiler was 6·56 feet in diameter, 25·75 feet long; flues 27·5 inches in diameter. The thickness of plates for the shell was 0·64 inch, for the ends 0·75 inch, and for the flues 0·5 inch. Furnaces internal. The "Fairbairn" boiler consisted of two cylinders, 4·1 feet in diameter, 25·75 feet long; with a central fire-tube through each cylinder, 27·5 inches in diameter. Furnaces internal. The two cylinders were united to a third above them, 3·75 feet in diameter, 23 feet long, by three neckings or pipes from each lower cylinder. The upper cylinder was made of ½-inch plates; the lower cylinders, of plates 0·54 inch thick; the flues were 0·52 inch thick, and the ends, 0·72 inch thick. The French boiler was 3·74 feet in diameter, and 29·5 feet in length. It had three heaters 1·64 foot in diameter, and 32·8 feet long, united by three neckings each to the boiler. The plates of the boiler were ½ inch thick, of the heaters 0·4 inch thick, and of the ends 0·56 inch thick.

The leading dimensions and quantities are subjoined for comparison:—

	Fairbairn.	Lancashire.	French.
Length of boiler . . . . . . feet	23 & 25·75	25·75	29·5 & 32·8
Total heating surface. . square feet	1,017	612	607
Length of grates . . . . . . feet	4·53	4·53	4·21
Combined width of grates . . do.	4·53	4·53	4·76
Total grate-area . . . square feet	20·5	20·5	20·1
Ratio of heating surface to grate-area.	1 to 49·5	1 to 29·8	1 to 30·3
Total capacity. . . . cubic feet	642·5	637·5	531·1
Water space . . . . do.	544·7	412·5	408·1
Steam space . . . . do.	97·8	225·0	123·0
Heating surface per cubic foot of water . . . . . square foot	1·87	1·48	1·49
Total weight with accessories . tons	19·6	16·6	14·5
Weight per square foot of heating surface . . . . lbs.	42·4	59·7	52·5

The fire-bars of the Fairbairn and the Lancashire boilers were 0·6 inch thick, with ¼-inch interspaces.

The products of combustion in the Lancashire boiler passed from the inside flues on each side to the front, and thence under the boiler to the chimney. In the Fairbairn boiler they passed from the flues by the sides of the lower cylinders, and returned by the sides of the upper cylinder, towards the chimney. In the French boiler the current was not divided, but after heating the three heaters, it wound round the boiler. The flues delivered into the same chimney. The temperature in the flues, just at the chimney, about 4 inches above the bottom, was taken every five minutes, by means of the nitrogen-thermometer of MM. Hirn and Hallauer.[1] The products of combustion were analysed by Orsat's apparatus.[2]

The feed-water was taken from the condenser of a neighbouring engine, and the temperature varied from 79° to 84° Fahr. The quantity of water was ascertained by a measuring vessel, from which it was drawn with regularity by a donkey pump. The measurement of priming water was effected by Hirn's process. The mean pressure of steam was maintained at from 4½ to 5 atmospheres. The steam was employed to drive two Woolf-engines.

Three series of trials were made: with best Ronchamp coal heavily fired; the same lightly fired; and with best Von der Heyt coal from the Saarbrücken district. For each boiler a preliminary trial, lasting two days, was made, in order to settle the conditions of the official trials. The coal consumed in getting up steam was included in the consumption. Two days before the trial, each boiler was emptied and thoroughly cleaned inside and outside, and the evening before the trial, steam was got up. In the first series of trials, with Ronchamp coal heavily fired, each boiler was tried for six days. The regular daily work was performed: the charging of fuel was commenced at 5 h. 15 m. A.M., when the pressure was got up, and the engine started about 6 A.M.; there

[1] *Vide* Bulletin de la Société Industrielle de Mulhouse. 1869, p. 543; 1873, p. 257; and 1874, p. 421.
[2] *Ibid.* 1874, p. 421.

was a pause at noon, for 1½ hour, after which the engine was again started, and worked till 6 P.M. For the second and third series of trials, each boiler was worked for three days. An extra three-days' trial of the Lancashire boiler was made with Ronchamp coal, to try the effect of increasing the supply of air; and this made up nine days' trial of that boiler.

The general results of the trials are given in the following table:—

RESULTS of COMPARATIVE TRIALS of STEAM BOILERS.

	Lancashire Boiler.	French Boiler.	Fairbairn Boiler.
RONCHAMP COAL.—HEAVY FIRING.			
	Mean of 9 days.	Mean of 6 days.	Mean of 5 days.
Mean pressure . . . . . atmos.	4·61	4·65	4·67
Total coal consumed . . . lbs.	4,220	4,445	4,082
Ash . . . . per cent.	14·1	14·1	13·8
Pure coal consumed. . . . lbs.	3,656	3,820	3,518
Water at 32° Fahr. evaporated do.	30,830	31,580	32,350
Do. per pound of total coal. . do.	7·31	7·06	7·93
Do. per pound of pure coal. . do.	8·51	8·22	9·19
Mean temperature of gases. Fahr.	572°	562°	421°
Volume of air drawn in per pound of total coal . . . cubic feet	183	194	226
RONCHAMP COAL.—LIGHT FIRING.			
Mean pressure . . . . . atmos.	4·66	4·64	4·63
Total coal consumed . . . lbs.	2,295	2,454	2,359
Ash . . . . per cent.	14·6	13·6	13·5
Pure coal consumed. . . . lbs.	1,958	2,146	2,067
Water at 32° Fahr. evaporated do.	17,610	18,110	17,970
Do. per pound of total coal . do.	7·67	7·38	7·64
Do. per pound of pure coal . do.	8·99	8·54	8·82
Mean temperature of gases. Fahr.	406°	425°	337°
Volume of air drawn in per pound of total coal . . . cubic feet	194	193	161
SAARBRÜCKEN COAL.			
Mean pressure . . . . . atmos.	5·13	5·10	5·10
Total coal consumed . . . lbs.	3,636	3,742	3,656
Ash . . . . per cent.	9·72	9·4	10·6
Pure coal consumed. . . . lbs.	3,279	3,400	3,270
Water at 32° Fahr. evaporated do.	23,330	24,130	24,880
Do. per pound of total coal . do.	6·41	6·45	6·81
Do. per pound of pure coal . do.	7·11	7·09	7·61
Mean temperature of gases Fahr.	554°	544°	402°
Volume of air drawn in per pound of total coal . . . cubic feet	180	179	195
GENERAL AVERAGES.			
Total coal consumed . . . lbs.	3,385	3,548	3,365
Water at 32° evaporated . . do.	23,930	24,330	25,070
Do. per pound of total coal. . do.	7·13	6·96	7·46
Do. per pound of pure coal . . do.	8·20	7·95	8·54
Mean temperature of gases. Fahr.	511°	510°	387°
Volume of air drawn in per pound of total coal . . . cubic feet	186	189	227

The subject of immediate interest was the comparative merits of the Lancashire and the French boilers, and in order to compare them directly, three days' performance of each was selected from the total number, averaging the same rate of evaporation, and the following were the average daily results for each boiler:—

		Lancashire.	French.
Ronchamp coal, total per day . . .	lbs.	4,298	4,293
Ditto, pure, per day	do.	3,682	3,695
Water at 32° Fahr. evaporated per day	do.	31,160	31,290
Ditto per pound of total coal . . .	do.	7·25	7·29
Ditto per pound of pure coal . . .	do.	8·47	8·47
Mean temperature of the gases .	Fahr.	587°	572°
Volume of air drawn in per pound of total coal	cubic feet	165	197

Showing an identity of performance, except in the volume of air drawn into the furnace.

The following are the weights and prices of the several boilers with their brickwork:—

	French.	Lancashire.	Fairbairn.
	Tons.	Tons.	Tons.
Weight of the boiler with accessories.	14·5	16·6	19·6
	£.	£.	£.
Price	442	563	657
Brickwork	120	112	120
Total	562	675	777
	£.	£.	£.
Interest and amortisation	56·2	67·5	77·7
	s. d.	s. d.	s. d.
Per day of 300 per year.	3 9	4 6	5 2

The Reporters are of opinion that these trials go to show that as regards economy of result, the design of the boiler is of little consequence, and that the truly important point is to have large heat-absorbing surface in relation to the coal burnt, and that the maximum evaporative efficiency of a boiler is obtained when 0·405 lb. of coal of medium quality is consumed per square foot of heating surface per hour.

D. K. C.

Trials with Meters for Feed Water. By C. H. Schneider.

(Civilingenieur, xxi., part 5 and 6, cols. 361–380.)

The Author publishes the results of experiments made in the "Sächsische Maschinenfabrik" at Chemnitz with water meters of Siemens, Frost, and Rosenkranz, during 1872–74. The instruments were fixed on to the feed pipe of a steam boiler with a steam pressure of from 4 to 5·5 atmospheres. As the feed pump was supplied out of a tank of known capacity, the exact quantity of water used could be noted and compared with the indications of the meters.

The feed pump was not constantly working, but supplied the boiler about thirty times a day, and the observations were made at the beginning and end of the day.

The data thus obtained are put together in tables which contain: Number of trial, date, time of trial (about ten and a half hours daily), quantity of feed water actually used (from 2,200 gallons to 3,520 gallons daily), number of times the pump was at work, quantity of feed water indicated by the meter, difference between this and the actual quantity, error for each kilogramme, and mean error out of each group of twelve trials.

The following abridged table contains the number of trial and the maximum, minimum, and mean error out of each group:—

Number of Trial.	Percentage of Error of the Siemens Water Meter.		
	Maximum.	Minimum.	Mean.
1 to 12	− 1·54	+ 0·02	− 0·03
13 „ 24	+16·98	− 0·29	− 0·55
25 „ 36	− 7·41	− 0·30	− 0·99
37 „ 48	+ 8·77	+ 0·21	+ 1·72
49 „ 60	−10·26	− 2·41	− 5·05
61 „ 72	−15·32	− 1·57	− 6·27
73 „ 75	−11·33	− 2·74	− 7·28
76 „ 87	− 4·72	− 0·19	− 2·00
88 „ 99	− 3·10	− 0·54	− 1·63
100 „ 111	−11·34	+ 1·08	− 3·59
112 „ 119	−19·25	− 1·98	− 8·47
120 „ 131	+ 4·02	− 0·53	− 0·15
132 „ 143	+24·59	+ 0·12	+ 3·32
144 „ 155	+10·92	+ 1·49	+ 3·86
156 „ 167	+13·53	0·00	+ 4·48
168 „ 179	+ 4·44	+ 0·11	+ 1·68
180 „ 191	− 6·09	− 0·55	− 0·51
192 „ 203	+14·81	+ 0·22	− 2·22
204 „ 215	− 7·52	− 0·10	− 2·45
216 „ 227	−13·01	− 0·28	− 1·26
228 „ 239	+ 9·25	+ 0·03	+ 2·55
240 „ 242	− 6·00	+ 0·27	− 0·31

Number of Trial.	Percentage of Error of the Frost Hot-Water Meter.		
	Maximum.	Minimum.	Mean.
1 to 12	+ 6·05	+ 0·15	+ 0·13
13 „ 24	−16·82	− 0·10	− 4·81
25 „ 36	−10·10	− 1·45	− 6·35
37 „ 48	− 5·82	− 0·30	− 1·12
49 „ 60	+ 6·48	− 0·64	+ 0·96
61 „ 72	+ 4·81	− 0·63	− 1·41
73 „ 84	− 6·89	+ 0·10	− 0·56
85 „ 90	+ 9·68	− 0·62	+ 4·65

Number of Trial.	Percentage of Error of the Rosenkranz Water Meter.		
	Maximum.	Minimum.	Mean.
1 to 12	− 6·11	+ 0·19	− 1·02
13 „ 16	− 6·84	− 0·73	− 1·4
17 „ 28	+11·31	+ 0·33	+ 2·79
29 „ 32	+ 1·83	± 0·40	+ 0·57

The probable discrepancy of one day's observation can be calculated from this table, and is for Siemens ± 2 per cent. to ± 3·8 per cent.; for Frost, ± 2 per cent. to ± 4 per cent.; and for Rosenkranz, ± 2·4 per cent. This exactness suffices for most practical purposes, and can always be obtained if the observations are made during a time long enough to exclude casual errors.

It is, however, necessary to ascertain from time to time whether the meter is in good working condition, which can be done by testing it with a known quantity of water. If a measured tank is not at hand, the boiler itself, after having been carefully cleaned, can be used.

G. Ka.

Note on the Steam Carriage of M. Bollée. By H. Tresca.

(Comptes-rendus de l'Académie des Sciences, Nov. 2, 1875, pp. 762–765.)

The steam carriage described has been designed and constructed by M. Amédée Bollée, of Le Mans, for the purposes of passenger and goods traffic, for the latter of which it acts as a traction engine. It accomplished the journey between Le Mans and Paris (a distance of about 150 miles) in eighteen hours, or about 8·3 miles per hour. The carriage, with water and coal, weighs 3·92 tons, or, with twelve passengers, about 4·66 tons. Of this weight 3·43 tons are carried by the driving wheels, which are 3·87 feet in diameter and 5 inches wide across the tires; the remaining 1·28 ton being supported by the two wheels of the fore carriage, which are 3·12 feet in diameter. Each wheel is placed between two pairs of springs, as close to the nave as possible, so as to minimise the bending strain upon the axle, which can thus be made of smaller dimensions. The driving wheels are loose upon the hind axle, while the two front wheels are quite independent of each other, and so arranged that the vehicle may be turned in a very small circle. An arrangement of chains wound on and off elliptical cam-barrels on the steering spindle, is employed to cause the front wheel, for the time on the inner side of the curve to be executed, to turn through the requisite number of degrees which are more than those to be turned through by the wheel for the time being on the outer side of the curve. The boiler is of the Field type, 2·62 feet outside diameter and 3·28 feet high, and contains a hundred and ninety-four $1\frac{1}{16}$-inch tubes. It supplies four cylinders, two of which, placed at an angle of 45° the one to the other, are allotted to each driving wheel, which they work independently through the medium of gearing and endless chains. The pistons are 4 inches in diameter, and of 6·25 inches stroke, and make, on an average, one hundred and eighty double strokes per minute. Every part of the carriage, boiler, and engine is made of steel, so as to secure lightness and strength. The driver's seat and the steam and guiding handles and pedals are all grouped in the front of the carriage, the reversing and cut-off being effected by a Stephenson's link motion. The right hand of the driver is devoted entirely to the steering handle, the other operations being effected by the left hand and foot. A stoker is employed to attend to the feeding of the boiler, by the Giffard injector or pump, and to replenish the tender with water, which is necessary at about every 7 miles. Bollée's carriage runs easily 12 miles per hour on the level, or from $7\frac{1}{2}$ to $9\frac{1}{2}$ miles on ordinary road, and can maintain a speed of about $5\frac{1}{2}$ miles per hour upon an incline of 1 in 20, drawing easily a weight equal to its own. Adopting a co-efficient of traction equal to 0·05, the engines

develop about 13 HP. at a speed of 9 miles per hour, at which speed the steering, even in town, is accomplished with precision; and horses are said not to be frightened by the machine, or by the slight noise it makes. W. W. B.

Compressed-air Tramway Car.

(Annales Industrielles, Jan. 2, 1876, pp. 17–21, 1 pl.)

A tramway car propelled by compressed air, on Mékarski's system, has recently been constructed, and is to be started on one of the Parisian lines of tramway. The car is in general outline on the model of the cars of the Compagnie des Tramways. The body is 11·5 feet in length, and accommodates twenty passengers inside; there is also room for fourteen passengers outside, on a spacious platform at the rear. Compressed air of 25 atmospheres is stored in eight cylindrical reservoirs of plate iron, from 12 to 16 inches in diameter, placed transversely underneath the carriage, and connected together. They are in two separate series; the capacity of the principal series is 52 cubic feet, and of the second or reserve series, 17 cubic feet. An upright reservoir, 14 inches in diameter and about 5 feet in height, is placed at the fore end of the car, and is three-fourths filled with water heated to 340° Fahr., through which the compressed air, required for consumption, is passed when it becomes saturated with vapour. The mixture of air and vapour occupies the upper part of the reservoir. The temperature of the water falls in proportion to the length of the journey; for a consumption of 52 cubic feet of air, 15 to 18 gallons of water are sufficient.

The pressure in the reservoir varies, of course, but the mixed air is wiredrawn by an automatic contrivance, which delivers the supply to the working cylinders at a uniform pressure, or at any pressure at the will of the conductor.

The frame of the car is of wrought iron, 5 feet 10 inches wide, and 18 feet 8 inches long. The car runs on two pairs of wheels about 28 inches in diameter, and placed 6 feet 10 inches apart. One pair of the wheels is driven by a pair of cylinders with expansive and reversing gear like that employed in locomotives; and the reciprocating parts are balanced by a sectoral weight on the axle opposed to each crank.

By the employment of air saturated with vapour, the engines may be worked with high degrees of expansion, so that the quantity of air consumed does not exceed 11 cubic feet per mile. The engines work without noise.

D. K. C.

Experiments made at the Mare Island Navy-yard, California, with different Screws applied to the United States Steam-Launch No. 4, to ascertain their relative Propelling Efficiency.[1]

By B. F. Isherwood, U.S.N.

(Journal of the Franklin Institute, April to December 1875, 78 pp.)

An extensive course of experiments was made in 1869–70, with different screws applied to the United States steam-launch No. 4, attached to the Mare Island Navy-yard, with the object of ascertaining the relative economic propelling efficiency of screws.

Hull.—The hull was of wood, and it was kept well painted and cleaned.

Length on load water-line, 54·40 feet; breadth, 11·88 feet; ratio, 4·58.

	Forward.	Mean.	Aft.
Load-draft from bottom of keel . .	2·457	3·156	3·855 feet.
Depth of keel	0·500	0·729	0·958 foot.

Immersed section		24·98 square feet.
Immersed surface, excluding keel and rudder . .		603·00 „
Do. do. including do. do. . .		717·00 „
Displacement, total	814·100 cubic feet, or	23·3 tons.
Do. per inch of draft at load-line . .	38·045 „	1·09 „
Distance of greatest cross section abaft middle of length on load water-line		3·42 feet.
Angle of dead rise at greatest cross section		13°·5

Top of rail above the water-line, 6 feet at bow, 3 feet 3 inches at centre, 4 feet 3 inches at stern.

Engines.—There were two vertical non-condensing engines, with link motion. The cylinders were $6\frac{3}{4}$ inches in diameter, with a stroke of 8 inches; the piston-rods were $1\frac{1}{8}$ inch in diameter. Total clearance at each end, 26·4 cubic inches. The feed water was fresh, and carried in a tank; it was heated to 125° Fahr. by the exhaust steam. The sides of the cylinders, with the steam pipes, were felted and lagged. The net weight of the engines, including the crank shaft, was 1,400 lbs.

The gross total weight of engines, boilers, and machinery was 10,000 lbs. The weight of feed water in the tanks was 8,500 lbs.

Screws.—The screws were cast of brass. Eight screws, lettered A, B, C, D, E, F, G, H, were tried, all of one diameter of blade, 4 feet 4 inches. The diameter of the hub or boss was 6 inches, except for the Griffith screw. Screws A, C, E, F, were formed by combinations of two double-bladed screws, exact duplicates of each other, of a uniform pitch of 5·136 feet, the blades of which were

[1] *Vide* Transactions of the Institution of Naval Architects, vol. xiii., 1872, p. 269, "On Quick Steam-Launches," by F. J. Bramwell.

$5\frac{1}{2}$ inches long in the direction of the axis. Screw A was formed by placing two together, so as to form one double-bladed screw 11 inches long. C was single double-bladed $5\frac{1}{2}$ inches long. E was formed by placing two screws together, having the blades of one at right angles to those of the other; practically making up a four-bladed screw $5\frac{1}{2}$ inches long. F (the Mangin screw) was formed by placing two screws together, the blades of one being immediately behind those of the other; making up 11 inches of length. D consisted of one of the screws cut shorter, at right angles to the axis, to a length of $3\frac{1}{8}$ inches. B was formed by joining up D to C, making a continuous screw $8\frac{5}{8}$ inches in length.

G had three blades, of expanding pitch; 6 feet 6 inches forward, and 7 feet 6 inches aft; mean pitch, 7 feet. The blades were curved lengthwise; the length at periphery was 7 inches; at 19 inches from the axis, 11 inches; and at the nave, 6 inches. In projection parallel to the axis, the forward edge of each blade was nearly perpendicular to the axis; it was a convex curve, having a versed sine of $1\frac{3}{8}$ inch at 19 inches radius. The thickness at the rear was $1\frac{1}{4}$ inch. The weight of the screw was 250 lbs.

H was a three-bladed Griffith screw, formed by trimming the blades of screw G into the Griffith form. The hub was made up of wood into a frustrum of a sphere 15 inches in diameter, and 11 inches long. The length of the blades, at the periphery, was $3\frac{1}{2}$ inches; at 19 inches radius, 11 inches; at the nave, $7\frac{1}{2}$ inches. In side view they were pear-shaped. The pitch expanded from 6 feet 8 inches to 7 feet 4 inches; mean, 7 feet. The fraction used of the pitch in function of the surface and of the propelling efficiency of the surface, was 0·24.

Screw.	Number of Blades.	Fraction used of the Pitch, adding all the Blades together.	Projected Area of the Blades at right angles to the Axis.	Helicoidal Area of the Blades.
			Square feet.	Square feet.
A	2	0·357	5·195	6·132
B	2	0·280	4·073	4·808
C	2	0·178	2·098	3·066
D	2	0·101	1·476	1·742
E	4	0·357	5·195	6·132
F (Mangin) .	4	0·357	5·195	6·132
G	3	0·345	5·014	6·852
H (Griffith) .	3	0·203	2·750	4·297

Trials.

Resistance of the Hull.—The thrust of the screw, and the horse-power applied to the propulsion of the vessel, at speeds of from 5 miles to 8·5 miles per hour, were as follows. Columns are added to show the squares of the speeds proportionally, taking the lowest

speed as 1; and the proportional resistances, taking the lowest resistance as 1:—

Speed.	Squares of the Speed Proportionally.	Thrust of the Screw.	Thrust Proportionally.	Horse-power applied at the Thrust Carriage to the Propulsion of the Vessel.
Geographical miles per hour.	Ratios.	lbs.	Ratios.	HP.
5·0	1·00	315·4	1·00	4·85
5·5	1·21	368·8	1·17	6·23
6·0	1·44	449·9	1·43	8·30
6·5	1·69	560·6	1·78	11·20
7·0	1·96	707·0	2·24	15·21
7·5	2·25	867·1	2·75	19·99
8·0	2·56	990·8	3·14	24·36
8·5	2·89	1,082·4	3·43	28·28

The resistance of the hull does not follow out the ratio of the square of the speed. From 5 miles to 6 miles per hour, the ratio is exactly that of the square. Thence the ratio is higher than that of the square, until at 7·8 miles per hour (not tabulated here) it is 23·3 per cent. in excess; but the excess is reduced to 18¾ per cent. at 8½ miles per hour. The deviation of the resistance from the ratio of the squares of the speed, is ascribed to the fact that the trim of the vessel varied with every variation of speed, the bow rising and the stern falling as the speed was increased.

Slip of the Screws.—The slips of the screws at the several speeds are as follows, expressed in percentages of the respective axial speeds of the screws; the axial speeds having been ascertained by multiplying the pitch by the number of turns in a given time, and the slip being the excess of this speed above that of the vessel. The average pitches are used in calculating the slip for screws G and H.

Speeds.	Slip of the Screws.					
	A, E, F.	B.	C.	D.	G.	H.
Geographical miles per hour.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
5·0	7·82	8·74	10·43	13·01	9·89	11·60
5·5	8·37	9·35	11·16	13·93	10·58	12·44
6·0	8·87	9·90	11·83	14·76	11·22	13·20
6·5	9·40	10·49	12·54	15·64	11·89	14·01
7·0	10·10	11·26	13·47	16·80	12·77	15·08
7·5	11·56	12·86	15·42	19·83	14·63	17·31
8·0	13·33	14·81	17·78	22·18	16·89	20·06
8·5	14·57	16·15	19·43	24·24	18·48	21·99

At all speeds there was no difference between the slips of A, E, F,

showing that, in the case of screws having the same kind and the same quantity of surface, their propelling efficiency in smooth water was not affected by either the number or the position of their blades.

Comparing the slips of the screws A, B, C, and D, which differ only in quantity of surface, it appears that the absolute slips of screws having the same kind of surface, and differing only in its quantity, were in the ratio of the square roots of the surfaces for the same speed of the vessel. The "absolute slip" signifies the actual speed of the water current—not as a percentage—caused by the screw in the direction opposite to that of the course of the vessel.

The slip of the three-bladed screw G, with expanding pitch, was greater than that of B, though it had nearly a half more surface. Screw H, a modification of screw G to the Griffith form, made still more slip than G. The slip at 8·5 miles per hour was raised from 18·48 per cent. with G, to 22 per cent. with H; but the surface had been to a certain extent reduced in changing from G to H.

The relative economic propelling efficiency of the screws was represented by the percentage of the net power developed by the engine and applied to the shaft, expended in the propulsion of the vessel. The percentages at the lowest and the highest speeds were as follows :—

Speeds.	Percentages of net Power expended in Propulsion.					
	A, E, F.	B.	C.	D.	G.	H.
Geographical miles per hour.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
5·0	79·81	80·71	79·96	78·84	76·78	77·24
8·5	74·05	74·05	71·82	68·43	69·53	68·00

From this table it appears that the propelling efficiency of screw B was the highest, excepting that screws A, E, F, possessed an equal degree of efficiency at the highest speed.

It is shown that, with the same pitch of screw, the balance of net pressure on the piston, deduction being made for the friction of the screw surface on the water, is the same at the same speed of vessel, independently of the screw surface and the slip, and that for screws of different pitches the balance of net pressure, as above, at the same speed of vessel, is in the direct ratio of the pitches, independently of other dimensions and of slip.

The particulars of performance in detail are here selected for screw B, which proved to be the most efficient and economical for the lowest and the highest speeds. The original tables give the performance in detail for each screw, and for speeds of from 5 to 8·5 miles per hour, advancing by ½ mile per hour.

RESULTS of TRIALS of SCREW B. DIAMETER 4 feet 4 inches, PITCH 5·136 feet, DOUBLE-BLADED, FRACTION of PITCH 0·280.

Speed of the vessel, in geographical miles, of 6,086 feet per hour	5·0	8·5
Slip of the screw, as a percentage of its speed, per cent.	8·74	16·15
Thrust of the screw by dynamometer . . . lbs.	315·4	1,082·4
HP. by dynamometer, applied to the propulsion of the vessel . . . . HP.	4·85	28·28
Double strokes of engine's pistons, and revolutions per minute	108·20	200·20
Proportional distribution of net Power applied to the Shaft—		
Friction of the load . . . . per cent.	7·50	7·50
Surface friction of the screw . . . . . . „	4·06	4·19
Slip of the screw . . . . „	7·73	14·26
Propulsion of the vessel . . . . „	80·71	74·05

Trials with Screw G, with the Vessel secured to the Wharf.—Two trials were made at two speeds, respectively at the rate of 99·9 and 35·73 revolutions per minute. The following are the chief results:—

		1st Trial.	2nd Trial.
Revolutions per minute	turns	99·90	35·73
Thrust of the screw G, by dynamometer	lbs.	1,093·50	154·50
Gross effective mean pressure on pistons, in pounds per square inch	„	100·00	15·70
Net pressure on pistons	„	98·00	13·70
Gross effective indicator HP. . . .	HP.	28·49	1·60
Net do. do. do. . . .	„	27·92	1·40
Dynamometrical HP..	„	24·83	1·26

RESISTANCE OF THE SCREWS TO DRAGGING THROUGH THE WATER.

The vessel was towed at different speeds through still water by a small tug; the tow-line was a small cord 170 feet in length between the vessels, and was attached to a dynamometer, through which the pull was measured. The vessel was towed at speeds of from 5½ to 7½ geographical miles per hour, when the resistance increased as the square of the speed, the extreme variation from this law, more or less, being only 2 per cent., and happening as often at low as at high speeds. At 7 miles per hour the resistance of the hull, averaged from all the dynamometer diagrams at all the speeds, and reduced in the above proportion, was 631 lbs.

When the launch was propelled by its own screw, the resistance of the hull was 707 lbs. The difference, 76 lbs., is 10·75 per cent. of the larger quantity, and is satisfactorily shown by Mr. Isherwood to be due to the shallower draught of water when the vessel was towed.

All the experimental screws, except screw G, were tested for resistance.

RESISTANCE of SCREWS to DRAGGING THROUGH the WATER, at 7 GEOGRAPHICAL MILES PER HOUR.

Screws.	Blade fixed Vertically.				Blade fixed horizontally.			
	Resistance.	Increase of Vessel's Resistance.	Decrease of Vessel's Speed.	Speed without Screw.[1]	Resistance.	Increase of Vessel's Resistance.	Decrease of Vessel's Speed.	Speed without Screw.[1]
	lbs.	Per cent.	Per cent.	Geo. miles.	lbs.	Per cent.	Per cent.	Geo. miles.
A .	350	55·47	19·80	8·73	440	69·73	23·24	9·12
B .	197	31·22	12·73	8·02	345	54·68	19·59	8·70
C .	90	14·26	6·45	7·49	220	34·86	13·89	8·13
D .	26	4·12	2·00	7·14	125	19·81	8·64	7·66
E .	Vertical and horizontal. 310	49·13	18·11	8·54	Diagonally. 337	53·41	19·26	8·67
F .	90	14·26	6·45	7·48	220	34·86	13·89	8·13
H .	One blade vertical below shaft. 283	44·85	16·91	8·42	..	..	..	..
	Do. above shaft. 361	57·21	20·24	8·78	One blade horizontal. 331	52·46	19·01	8·64

SCREWS REVOLVING FREELY.

Screws.	Revolutions per Mile, at all Speeds, from 5¼ to 7½ Miles per Hour.	Difference of Axial Speed of the Screw, and the Speed of the Vessel.	Resistance.	Increase of Vessel's Resistance.	Decrease of Vessel's Speed.	Speed without Screw.[1]
		Less per cent.	lbs.	Per cent.	Per cent.	Geo. miles.
A .	921	22·28	134	21·24	9·18	7·70
B .	921	22·28	105	16·64	7·41	7·56
C .	921	22·28	67	10·62	4·92	7·36
D .	757	36·12	54	8·56	4·02	7·29
E .	921	22·28	134	21·24	9·18	7·70
F .	921	22·28	67	10·62	4·92	7·36
H .	665	23·51	125	19·81	8·64	7·66

[1] Speed, in geographical miles per hour, that the vessel would have had with the screw removed, had the vessel been towed by the pull of the aggregate resistance of vessel and screw by dynamometer.

During a continuous trial, of 9·18 hours duration, made to ascertain the evaporative performance of the boiler, the vessel was secured to the wharf, and the distribution of the indicator HP. was as follows, the vessel being at that time fitted with screw G:—

Gross indicator HP.	27·22
Power required to work the engines and shafting, *per se*	0·67
Net indicator HP. applied to the shaft	26·55 or 100

Power absorbed by the friction of the load . .	1·99 or	17·5 per cent.
Do. do. surface friction of screw . . .	1·46 „	5·5 „
Do. expended in displacement of water by screw	23·10 „	87·0 „
	26·55	100·0

D. K. C.

On the Production of Coal, Iron, and Steel in the Prussian States in the Year 1874.

(Zeitschrift für das Berg-, Hütten- und Salinenwesen, vol. xxiii., part 4, pp. 20–34.)

In the year 1874 there were four hundred and sixty-six collieries working, in addition to forty-two not working and new winnings. Brown coal or lignite was wrought in five hundred and thirty-five mines, besides sixteen new or suspended winnings. There were nine hundred and seventy mines raising iron ore, and two hundred and two suspended. The production was as follows:—

—	Total.	Colliery Consumption.	Number of Hands.			Total.
			Underground.	Surface.		
	Tons.	Tons.		Men.	Women.	
Coal .	31,938,683	2,155,821	129,422	29,608	2,472	161,502
Lignite .	8,716,649	588,478	12,343	6,188	114	18,642
Iron ore .	2,540,886	..	17,516	5,121	1,134	23,771

NOTE.—The quantities are expressed in metrical tons of 1,000 kilogrammes, about 1½ per cent. less than the British statute ton.

The employment of women on the pit banks is almost entirely confined to the province of Silesia.

	Tons.
The average production of coal per underground hand was .	247[1]
Do. do. lignite	706[1]
Do. do. iron ore	145

The number of fatal accidents in coal mines was four hundred and eighty-four, equal to 2·988 per thousand hands employed and 1 per 66,217 tons raised. In lignite mines the number was thirty-eight, equal to 2·043 per thousand, or 1 per 229,389 tons raised. The greater security of lignite mining is to be ascribed to the large proportion of open works, the small use made of gunpowder, and the absence of fire-damp. Curiously enough, the proportion of deaths from suffocation, in badly-ventilated lignite mines, was exactly the same as that from explosions of fire-damp in coal mines, viz., 0·216 per thousand.

Of the total amount of iron ore raised 142 tons were consumed in the raw state, the remainder being smelted.

[1] These figures are not strictly comparable, as some proportion of the hands returned as above ground, in lignite mining, are employed in getting it in open workings, whereas the getting of coal is entirely performed by the underground hands. If, however, the whole number be so considered, the average per hand will be about 480 tons.

Of blast furnaces smelting iron ores, the total number was 348, of which 104 were out of blast: the remaining 244 were blowing for a total of 2,111¼ furnace-months, equal to an average period of blast of 8⅔ months per furnace. The total iron-producing material melted was 3,596,619 tons, made up of the following items:—

	Tons.
Iron ores, inland	3,265,641
Do. foreign	184,210
Forge and mill cinder	146,768

The difference between the amount returned as inland ore and that given previously as the produce of the mines, represents the import from other German states within the Customs boundary.

The total yield of pig iron was 1,280,269 tons, equal to a yield of 35·6 per cent. and a production of 140 tons per furnace per week. The yield of the foreign ores was 42·1 per cent.

According to the fuel employed, the blast furnaces were classified as follows:—

—	Number of Furnaces.	Number of Works.	Foundry Pig and Castings.	Forge Pig.	Steel-makers Pigs.	Average Weekly Make.
			Tons.	Tons.	Tons.	Tons.
Mineral fuel .	158	78	76,599	886,295	228,796	204
Charcoal . .	74	70	45,968	15,972	8,601	25[illegible]
Mixed fuel .	12	12	2,717	15,283	40	49½

The total number of hands employed in the production of pig iron and first-fusion castings was 19,001, including 741 women.

The total consumption of pig iron in 1874 was as follows:—

Purpose.	Inland.	Foreign.	Together.
	Tons.	Tons.	Tons.
Foundry use	83,065	205,527	288,592
Malleable iron . . .	1,170,126	27,831	1,197,957
Steel (forge processes) .	129,554	47,006	176,560
	1,382,745	280,364	1,663,109
Add casting run from blast furnaces			35,686
Add pig iron used in the production of steel, at the rate of 100 : 70			367,059
Making a total consumption of			2,065,854
The total produce of the blast furnaces was			1,280,219
Leaving an excess of consumption over production, without allowing for export or stock			785,635
In 1873 the corresponding excess was			426,991
In 1872 " "			463,210

The number of mills and forges was, 156 working upon cast iron, and 140 working scrap iron and purchased blooms. The former included 1,468 puddling furnaces and 90 open finery fires. The production per puddling furnace varied in the different districts

from 67·8 tons to 821 tons per annum, the average being 595 tons. The production of the open fires varied from 10 tons to 1,003 tons, the average being 347 tons.

The puddling and finery forges consumed 1,197,957 tons of pig iron, including 27,831 tons of foreign origin, and produced 904,224 tons of finished iron and bloom. The scrap and bloom forges produced, from 120,235 tons of waste and scrap iron and 123,073 tons of puddled bars and blooms, 184,900 tons of finished iron. The total quantity of finished iron retained for use in both classes of mills and forges was 12,799 tons. The total number of hands employed in the production of malleable iron was 43,529, including 473 women. The total outturn in finished iron is given in the classified table below, as well as that of steel.

The steel works were classified under two heads, thirty-eight being described as crude-steel works, working upon pig iron and selling a portion of their product as blooms, and thirty-two as cast-steel works, making only finished products. Of the total pig iron worked up by the former class, amounting to 176,559 tons, 47,006 tons were of foreign origin. The total number of hands employed in both classes of works was 22,883. The crude-steel works produced 13,706 tons of bloom and finished steel, of which amount 1,549 tons were retained for works' purposes. The cast-steel works produced 234,721 tons of finished cast steel, including 1,855 tons used on the works. The relative proportion of the produce assignable to the different classes of processes is as follows:—

Process.	Number of Furnaces.	Total Produce. — Tons.	Average per Furnace per Annum. — Tons.
Puddling	369	170,441	462
Open-fire	10	324	32
Bessemer	56	167,924	3,000
Martin-Siemens	28	15,803	565
Cementation	6	1,900	316
Crucible	83	4,604	50

The amount under "puddled steel" includes about 550 tons of iron, and about one-third of the work assigned to the open-fire process was shear-steel refining.

The total production of finished iron, classified according to uses, was as follows:—

	Iron. — Tons.	Steel. — Tons.
Rails and fish-plates	253,638	225,193
Bridge and girder iron	74,015	..
Railway wheels, tires, and axles	12,836	49,914
Heavy special objects, forgings, &c.	37,248	5,529
Artillery and projectiles	..	6,683
Black plate and sheets	95,442	2,690
Tin plates	7,170	..
Wire	81,315	96
Tubes	3,163	..
Other kinds	371,578	54,276

H. B.

The Production and Consumption of Coal. By VICTOR BOUHY.

(Revue Universelle des Mines, January and February 1875, pp. 109–145.)

The Author ranges the countries which at the present time are the largest producers of coal in the following order: 1, England; 2, the United States; 3, the Zollverein; 4, Belgium and France; 5, Austria, including Hungary, and shows in a table the annual production in the first four of these groups. The fifth group gave, in 1872, about $\frac{1}{6}$ of that furnished by the fourth group.

The development of this branch of mining industry has not proceeded equally in each of these countries. England has always furnished more than half the production of the whole world. Previous to the year 1830, her share amounted to $\frac{3}{4}$ of the total production; in 1845, to a little more than $\frac{2}{3}$; in 1858, it was still above $\frac{1}{2}$; in 1865 and 1868, the same proportion of about $\frac{3}{5}$ was maintained; and in 1872 it still exceeded the half by more than 7,000,000 tons. From 20,000,000 tons in 1830, the product had risen, in England, to 131,639,993 tons in 1872; that is, in forty-two years, it had successively increased by more than 558 per cent. No accurate statistics of the production of the United States in 1830 are obtainable; but judging from those relating to the year 1845, it may be admitted that at the former date they occupied the fifth rank after England, Belgium, France, and Prussia. In 1872 they are in the second rank, with the important figure of 42,800,000 tons; that is, for the period of forty-two years, an increase of 2,950 per cent. The Zollverein produced in 1830 less than Belgium and France—about 1,200,000 tons, exclusive of lignite. In 1872 this group figures for 33,400,000 tons of coal; that is, an increase of 2,680 per cent. in forty-two years. Moreover, in addition to this quantity of coal, there were raised, in 1872, about 9,018,000 tons of lignite. The production of Belgium, which in 1830 amounted to 1,913,677 tons, had reached in 1872 a value of 15,658,948 tons; or an increase of 718 per cent. in forty-two years. At the former date Belgium occupied the second rank; at the latter date it had fallen to the fourth. The production of France has risen from 1,596,570 tons in 1830, to 15,204,170 in 1872; thus showing an increase in the forty-two years of 852·9 per cent. This country occupied at the former date the third place after England and Belgium; but at the latter date it was nearly on an equal rank with Belgium, in the fourth place after England, the United States, and the Zollverein. Austria produced in 1830 210,000 tons of coal and lignite; in 1860 the product of coal alone amounted to 1,948,189 tons, and in 1872 to 4,764,786 tons. It will be observed that the produce of France is constantly tending to equal that of Belgium; and it seems probable that the latter country will soon be left behind by its neighbour. This result is also indicated by the fact of the increase during the interval of forty-two years, between 1830 and 1872, being 718 per cent. in the case of Belgium, and 852·9 per cent. in the case of France. This

notable increase of the production in France is due mainly to the great development of the mining industry in the departments of the north, and especially in the Pas-de-Calais. The Author shows that these departments furnished 29 per cent. of the total production of France in 1834, and 39·04 per cent. in 1872. In the former year the quantity raised was only 4,103 tons; in 1873 it had increased to 2,978,647 tons. This coalfield would seem to be yet hardly touched; and the intelligence and skill which have been shown in laying out and opening up the workings in this locality, together with the readiness with which capital has been placed at the disposal of the engineer, are evidences that the future of this northern field will be marked by yet greater success.

In the Département du Nord the total superficial extent of the ten concessions into which that district is divided is 152,000 acres, thus giving an average of 15,200 acres to each concession or company. The twenty concessions of the Pas-de-Calais amount to a superficial extent of 128,600 acres, or an average of 6,430 acres to each concession, a much smaller surface than that held in the Département du Nord. If these areas be compared with those of the concessions of the Hainault district, in Belgium, the coal basin of which presents, with that of the departments of the north of France, marked analogies of formation and composition, it will be found that in 1872 there were in that district one hundred and thirty mines, having together a superficial extent of 226,000 acres, or an average of 1,739 acres each. Thus the mean of the Hainault district is much inferior to that of the northern districts of France, the average of which is 6,428 acres.

In a table the Author shows the production between 1860 and 1873 per hectare of concession for the departments Nord and Pas-de-Calais, and for Hainault, Belgium, the number of drawing shafts in operation in the same districts, and the average out-put per drawing shaft.

It appears from this table that the production per hectare in the two French groups is greatly inferior to that attained in the Belgian group, since the mines which were being worked in 1873 furnished 69·15 tons in the Département du Nord, 59·79 tons in the Pas-de-Calais, and 167·83 tons in the Hainault district. But judging by the figures which show the mean annual produce per shaft, the work is executed under better conditions in the two French groups than in the Belgian group; for, since the year 1871 in the Département du Nord, and since the year 1862 in the Pas-de-Calais, a larger quantity has been raised through one drawing-shaft than in the Hainault district. In 1873 the difference in this respect is very sensibly in favour of the French groups, for the mean quantity per shaft drawn in that year was 73,133 tons in the Département du Nord, and 74,567 tons in the Pas-de-Calais; while in the Belgian district it was only 57,687 tons. From these facts the Author concludes that the northern coalfields of France have a great future before them, and that they will be capable of supplying the whole needs of the country. If,

he says, in the Belgian basin there is a drawing-shaft for every 1,119 acres of surface, whilst in the north of France there is only one drawing-shaft for every 3,321 acres, it is evident that, by multiplying the number of shafts by one and a half, assuming the other coalfields to continue at their normal rate, enough coal may be raised to render France wholly independent of other countries. Even in such a case there would be only one drawing-shaft for every 1,290 acres, a less favourable condition than that in the Hainault district, and especially in the basins which offer the greatest analogy to those of the north of France, namely, those known as the Couchant de Mons and du Centre, in which, in 1873, there was one drawing-shaft in operation for every 621 acres.

The Author concludes this portion of his report with statistics relative to the total coal production of the world in 1872:—In Europe, England furnished 131,640,000 tons; in America, the United States furnished 42,794,000 tons, a large portion of which was anthracite; and Nova Scotia, Chili, and British Columbia, 810,000 tons. In Australia, New South Wales furnished 1,300,000 tons; and Queensland and New Zealand, 47,000 tons. And in Asia, India furnished 650,000 tons; and Japan, China, and Burmah, 44,000 tons. The total quantities amount to 248,144,200 tons, of which England furnished more than half.

The second part of the report is devoted to the consumption of coal, and in a table it is shown that it has increased during the ten years ending 1872, in the Zollverein by 116 per cent., in France by 35·6 per cent., in England by 47 per cent., and in Belgium by 45·5 per cent.; and the increase in these countries during the thirty years preceding the above-mentioned date was 1,460 per cent., 324 per cent., 249 per cent., and 227 per cent. respectively. The increase in the Zollverein is very great relatively to the other countries, and in France it is especially remarkable. In both cases the increase is mainly due to the development of metallurgical industry and the extension of railways. As a consumer of coal France takes the fourth place after England, America, and the Zollverein; but England, it will be observed, has an enormous lead. It appears from the statistics which have been prepared that there are at present but three countries in the world that raise more coal than they consume—namely, England, Belgium, and the Zollverein, which consequently export that mineral in considerable quantities.

About one-third of the requirements of France is imported from neighbouring countries, three-fifths of which quantity is obtained from Belgium. From this fact it is evident that Belgium is deeply interested in the development of the mineral industry of France, and that the price of coal in the former country will largely depend in the future upon the increase of production in the latter.

G. G. A.

Calorimetric Trials and Analyses of Coals and Lignites.

By M. A. Scheurer-Kestner and Charles Meunier-Dollfus.

(Bulletin de la Société Industrielle de Mulhouse, June 1875, Table.)

A tabular statement, of which the annexed is an abstract, is given of the results of the labours of the Authors in the analysis and testing of coals and lignites, which have been published successively at different periods, in foreign periodicals, since 1868, to the end of 1874. They state that, since the commencement of their labours, MM. Jamin and Amaury have demonstrated that the specific heat of water varies sensibly between the temperatures at which their trials were made; and that the employment of the formula of these gentlemen would augment by about 2 per cent. the tabulated quantities of the heat of combustion. The trials for the heat of combustion were conducted by means of the quick-combustion calorimeter of MM. Favre and Silbermann.

All the numbers in the table have reference to the substance dry and pure; that is to say, to the combustible dried at 212° Fahr., and free from ash.

Analysis of French and other Coals and Lignites, and the observed Heat of Combustion.

Designaton of Combustible.	Gaseous Elements.			Heat of Combustion of 1 lb. of pure Fuel.
	Carbon.	Hydrogen.	Oxygen and Nitrogen.	
Coal.	Per cent.	Per cent.	Per cent.	English units.
Ronchamp, 3 samples	88·59	4·69	6·72	16,416
Saarbrücken, 7 "	81·10	4·75	14·15	15,320
Creusot, 4 "	90·60	4·10	5·30	16,994
Blanzy—Montceau	78·58	5·23	16·19	14,985
Do. anthracitic	87·02	4·72	8·26	16,400
Anzin	84·45	4·21	11·32	16,663
Devain	83·94	4·43	11·63	16,290
English—Bwlf	91·08	3·83	5·09	15,804
Do. Powell-Duffryn	92·49	4·04	3·47	16,106
Russian, Grouchefski, anthracitic	96·66	1·35	1·99	14,866
Do. Miouchi, bituminous	91·45	4·50	4·05	15,651
Do. Goloubofski, flaming	82·67	5·07	12·26	14,438
Lignites.				
Rocher bleu	72·98	4·04	22·98	11,670
Manosque, bituminous	70·57	5·44	23·99	13,253
Do. dry	66·31	4·85	28·84	12,584
Bohemian, bituminous	76·58	8·27	15·15	14,263
Russian, Toula	73·72	6·09	20·19	13,837
Lignite passing to fossil wood	66·51	4·72	28·77	11,444
Fossil wood passing to lignite	67·60	4·55	27·85	11,360

D. K. C.

On the Coking Properties of the Coals of Saarbrücken.

By DR. A. SCHONDORFF.

(Zeitschrift für Berg-, Hütten- und Salinenwesen, xxiii., part 3, 1875, pp. 135–162.)

The chemical and physical properties of coals are, as the Author points out, liable to considerable variations for the same ultimate composition; and therefore chemical analysis alone is not sufficient to fix their technical value. This is partly due to the difficulty of accurately determining the constituents; the common practice being to determine only certain constituents directly, assuming the difference from 100 to be oxygen and nitrogen, which in this way are affected by the whole of the errors of the analysis. In like manner, too large a proportion of oxygen and hydrogen may be reported in the analyses of very ashy coals or bituminous schists, owing to the circumstance that the ashy matter, which is of the nature of clay, may retain a notable proportion of water of hydration, which is not driven off below a red heat, and therefore goes to increase the amount of water and carbonic acid produced in the combustion furnace. The Author considers, therefore, that the test of coking properties, as made by subjecting a portion of the coal in a fine powder to a strong red heat in a covered platinum crucible, until the evolution of illuminating gas has ceased, is the best measure of quality for practical purposes; the amount of ash being afterwards determined by the complete combustion of the coke. The quantity of coke yielded is a measure of the fitness of the coal for particular purposes; for, as a general rule, it may be assumed that the lower the percentage of coke, the greater will be the amount of inflammable gases; such coals being best adapted for reverberatory furnaces and smithy purposes, while those in which the coke yield is greater are best fitted for raising steam, and for heating purposes generally.

The Author then gives the results of two hundred and eighty-two coking trials, upon the different seams in the Saarbrücken coal-field, arranged in stratigraphical order from above downwards, classifying the qualities of coke obtained according to the following scale—based upon the appearance presented by the free upper surface exposed in the crucible:—

Surface.	Colour.	Cohesion.	Quality of Coal.
Rough and finely granular (sandy)	Black	Loose all over or near edge	I. Sand coal.
Do.	Do.	Loose in the centre, compact at edges . . .	II. Sintered sand coal.
Do.	Do.	Compact all over . . .	III. Sinter coal.
Do.	Grey	Hard and warty . . .	IV. Caking sinter coal.
Smooth	..	Metallic, lustrous, and hard	V. Caking coal.

The results obtained by comparing the coking yield of the seams with their geological positions indicate generally that the yield

increases generally with the age, as does the caking character, the amount of hygroscopic water diminishing in the same order, as shown in the following abstract. The Roman figures refer to the classification given above; the proportional numbers represent the number of results obtained in each class. The coke is calculated as pure—that is, free from ash and water.

Position.	Hygroscopic Water.	Coke.	Number of Results in each Quality.				
		Per cent.	I.	II.	III.	IV.	V.
1. Upper seams . .	6·10	62·37	2	1	1	0	0
2. Middle series, upper division . . .	4·73	64·87	24	21	20	4	0
3. Middle series, lower division . . .	4·13	63·16	4	5	13	17	8
4. Lower seams . .	2·76	66·71	2	5	10	34	111

From which it follows that the most valuable coking and gas coals are those of the lower measures.

The Author then considers the classifications of coals proposed by Hilt and Gruner—in which their properties are measured by the proportional coke yield—and shows that they cannot be taken as applicable to the coals of Saarbrücken.

The second part of the Memoir (p. 150) treats of the physical structure of the coals which are separable into glance coal, dull coal, striped coal—made up of alternations of dull and bright portions,—and fibrous, or soot coal, showing distinct indications of vegetable fibre (the so-called mother-of-coal of English geologists). The different seams are made up of these different substances in variable proportions, the most usual condition being an alternation of bright and dull stripes, the extreme proportion of the latter being found in cannel—which, however, is never entirely free from bright portions.

The relative coking power of these different substances is then shown, in a table representing the results obtained from the examination of a particular group of seams. An average sample of the coal was first coked, and then the different components were picked out and treated separately. The first example taken out of this table is as follows:—

	Yield of Coke.	Quality.
	Per cent.	
Average of whole seam	65·0	III.
Dull striped portion picked out .	56·0	V.
Bright glance coal do .	63·2	V.
Fibrous coal	79·5	I.

The results of the investigation show generally that both the bright and the dull-striped coals are fit for gas and coke-making; but the former, from their comparatively higher yield, are to be considered as more especially coking coals; the latter being better for gas-making. The fibrous coal is bad for either purpose, as it lowers the coking quality and weakens the coke, and at the same time gives only a small amount of gas, of low illuminating power; when present in quantity, it is necessary to mix it intimately with

the other components of the coal, if it is desired to make a dense and uniform coke; and for this purpose it may be advisable to grind the coal in a disintegrator before introducing it into the coke oven.

The Author concludes that these three qualities of coal point to their origin from different parts of the plants that have gone to make up the mass of the seam. The fibrous portions are directly referable to the transformations of woody fibre by a process analogous to carbonisation; while the glance coal results from the mucilaginous portions of the plant insoluble in water; and the dull, or striped portion, from the soluble matters, gum or dextrin, the latter being produced mainly by transformation from cellulose under the action of nitrogenous ferments.

He also considers that there is some probability in Mohr's hypothesis of the origin of coal from seaweed; but that such a view is not exclusively necessary.

H. B.

Fuel and its Use. By Prof. H. Fritz, of Zurich.

(Dingler's Polytechnisches Journal, Band 219, 3, pp. 185–202.)

Although frequent attempts have been made to render the use of fuel as advantageous as possible, the results are far from satisfactory, as only part of the heating power is utilised. The difference between theoretical and effective heating power for various sorts of fuel may be seen by the following table, which gives the number of pounds of water evaporated by 1 lb. of fuel.

Fuel.	Heating Power.		
	Theoretical.	In Steam Boilers.	In open Boilers.
Petroleum	16·30	10—14	..
Anthracite	12·46	..	..
Coal	11·51	5·2—8	5·2
Charcoal	10·77	6—6·75	3·7
Coke	9—10·8	5—8	..
Brown coal	7·7	2·2—5·5	1·5 —2·3
Peat	5·5—7·4	2·5—5	1·7 —2·3
Wood	4·3—5·6	2·5—3·75	1·85—2·1
Straw	3·0	1·86—1·92	..

As regards the heating of steam boilers, Mr. Thompson found, by a series of experiments, that, on an average, only 47 per cent. of the theoretical heating power of the fuel is utilised, the remainder being lost through imperfect combustion, radiation, and other causes. Since portable engines have been arranged for straw-burning, this fuel has become of great importance for agricultural purposes. Trials at the Vienna Exhibition proved, that 1 lb. of

straw is capable of evaporating from 1·81 lb. to 1·97 lb. of water into steam of 70 lbs. pressure and 305°·6 Fahr. Compared with Thompson's figure for other fuels, straw would seem to give more work than even coal; but the trials in Vienna were made with Exhibition engines and under the most favourable circumstances.

Amongst the other caloric engines tried up to the present time, only those working with hot air, exploding gas, and exploding vapour of petroleum have proved of practical use. The following table shows the comparative merits of different systems:—

Air Engines.	Pounds of Fuel per Hour, and HP.	Relation between Effective and Theoretical Work of Fuel.
Belou	3·3—4·84	6·0—4·1
Leawitt	6	3·5
Lehmann	10·12	1·9
Leauberau	9·9—13·15	2·0—1·4
Ericsson	11—16·5	1·8—1·2
Gas Engines.	**Quantity of Gas reduced to Coal in lbs.**	
Otto and Langen	3·96—6	5·0—3·5
Hugon	9·9	2·0
Lenoir	9·9—12	2·0—1·8
Petroleum Engine.	**Petroleum in lbs.**	
Hock	1·65—2·86	8·4—4·6

Comparing the different steam engines with these motors, it is found that as regards work they are nearly equal, or rather, the duty varies for steam engines and other caloric motors almost between the same limits. To show this, the following table is arranged according to the work of the different motors:—

	Per cent.
Small high-pressure engine without expansion	1·8
Air engine, Ericsson	1·8
" Leauberau	1·8
" Lehmann	1·9
Gas engine, Lenoir	2·0
" Hugon	2·0
Portable steam engine	2·8
High-pressure steam engine with expansion	3·0
Air engine, Leawitt	3·5
" Belou	4·1
Condensing engine with expansion	4·5
Gas engine, Otto and Langen	5·0
Petroleum engine, Hock	8·4
Large steam engines, best make	9·0

Although according to this table the work of high-pressure steam engines is less than that of gas or air engines, the cost of fuel for the latter still exceeds that for steam engines from 2·5 to 5 times, a circumstance which explains the fact that, notwithstanding the many advantages of air or gas engines, they are not able to replace the ordinary high-pressure steam engine.

G. KA.

Boring for Coal with a Diamond Borer, near Pristoupin in Bohemia. By PROF. W. BUKOVSKY.

(Mittheilungen des Architekten- und Ingenieur-Vereins in Böhmen, No. 1, 1875, pp. 21–23, 1 pl.)

The Austrian State-Railway-Company determined to bore for coal at this spot, and employed an English engineer to superintend the operation. The results obtained may be of interest. The motion was gained by means of a stationary engine driving a band and pulley shaft gearing into the head of the boring rods by a series of bevel-wheels. These boring rods were tubes 2 inches in diameter, bored from solid steel bars, used in lengths of 50 feet, made up of single pieces of about 8 feet long each, screwed together; the boring end being widened out to 3 inches diameter for a height of 9 inches. On the periphery of the borer were set from eight to twelve black Brazilian diamonds, protruding very slightly.

The detritus was removed by pumping water through the tubes, which made its escape through slits, and was carried up the space between the outside of the rods and the bore-hole; the water being conveyed by means of leathern hose fitted with brass nozzles. The weight of the boring rods was relieved by balance-weights. At a depth of 1,500 feet, the operation of removing or refitting the rods occupied two hours.

Work commenced on the 11th of July, 1874, and by the end of the month a depth of 313½ feet had been reached. The following table of results obtained in October may be interesting:—

PROGRESS MADE DURING OCTOBER 1874 THROUGH COARSE CONGLOMERATE MINGLED WITH QUARTZ PEBBLES.

Date.	Depth in Feet and Inches. From.		To.		Actual Boring.		Actual Time occupied.	
	Feet.	Ins.	Feet.	Ins.	Feet.	Ins.	H.	M.
7	1,334	7½	1,355	1½	20	6	6	45
8	1,355	1½	1,369	4	14	2½	18	40
9	1,369	4	1,390	4	21	0	9	40
10	1,390	4	1,420	1½	29	9½	24	0
11	1,420	1½	1,446	4	26	2½	24	0
12	1,446	4	1,464	4	18	0	19	45
13	1,464	4	1,490	8	26	4	24	0

The apparatus gave the greatest satisfaction, and saved much time as compared with other systems employed for similar purposes.

H. T. M.

Results of the Working of Pernot's Furnace at Ougrée.

(Oest. Zeitschrift für Berg- und Hüttenwesen, No. 42, p. 444.)

This furnace, which was started in the middle of November 1874, has been employed since that time in puddling iron. In January 1875 the average yield was 9 tons of blooms per twenty-four hours from 10 tons of metal charged, with a consumption of 15 cwt. of coal per ton of bloom. The loss of iron in the slags was about the same as in the old furnaces. The coal used was of a class not well suited for use with a blast under the grate; but, notwithstanding this disadvantage, the furnace was estimated to be equal to three of the old class of hand furnaces. In the month of February the results were not quite so favourable, the production being reduced to 8·5 tons, and the consumption of coal to 16 cwt. The iron produced was of a good, fibrous character, suitable for making into thin sheets.

The same hearth bottom was in use from the 7th of November to the 31st of March. The roof was in very good condition, being only slightly and uniformly reduced by wear.

From the middle of March the furnace has been used in puddling for grain, with better results than those obtained with fibrous iron.

The daily production was about 9 tons from ten charges of 1 ton each. The quality of the iron was that known on the works as No. 3, or the highest class; that of the ordinary furnaces being the lower, Nos. 1 and 2. The working of a charge lasted one hour and fifty-five minutes, divided as follows:—

	H.	M.
Charged at	9	10
First turning over	9	37
Second do.	9	43
Charge melted down	9	55
Last ball drawn[1]	11	5

The results of another day's working weighed as follows:— 6·48 tons of metal charged gave 6·025 tons of blooms with a consumption of 6·630 tons of coal, giving a consumption per 100 of blooms of 107½ of pig metal and 110 of coal. The charge consisted of ⅔ white spiegel of Ougrée, containing 5 to 6 per cent. of manganese and ⅓ of ordinary forge pig-iron; the loss being from 7 to 8 per cent., as against 15 per cent. in hand puddling.

It is found that a certain amount of hand work is necessary in

[1] The number of balls is from seventeen to eighteen, which are made up by two hands working independently. It is found most convenient when the iron comes to nature to divide the bed into eight segments, making two balls in each.

turning over the charge, as the portion in the centre of the bed easily comes to nature and forms into grains, which must be removed towards the circumference, in order to prevent its balling too soon. The furnace, when at work, requires two puddlers, a fireman, and an engineman.

H. B.

Improvement in Blast Furnace Construction.

(Engineering and Mining Journal, September 4, 1875, p. 237.)

The North Jersey Iron Company are now erecting several new furnaces embodying a number of improvements. The main object of the designers has been "to reduce the amount of material employed and labour required in the construction of a stack to the minimum having due regard to the permanency of the structure and its economic operation."

The old type of blast furnaces is a massive square stack, with Gothic arches leading to the tuyere openings. These have, in later years, given place to more symmetrical masonry piers, with iron mantles over the tuyere openings, or to heavy iron columns and mantles. The design of the furnaces under consideration is claimed as a still further improvement in the substitution of heavy iron housings, which rising to nearly double the height of the ordinary columns, expose more of the bosh walls to the cooling action of the atmosphere. The bosh walls are of fire-brick, 30 inches thick, and each course is secured by bands of 1 inch square iron, extending from one housing to another, into which they are secured by means of slots and T heads. The short space permits the use of light irons, which cover but a small portion of the brickwork. The housings support a hollow mantle, which allows of a free circulation of air, and also carries in openings cast in the wet the blast-water- and spray-pipes, so as to require but short lengths, and have them so exposed that they may be readily examined. The crucible walls, up to the level of the tuyere arches, are surrounded by a casing of plate iron, allowing space for a layer of 6 inches of washed gravel, through which water can percolate. A spray pipe runs underneath the mantle, and can be made to play against the bosh walls and cool them when required. The upper portion of the stack is built of red brick and lined with fire-brick, with the usual loam spaces between them. The red brick is secured by bands encircling the stack, having improved double clevices. The top of the stack has the usual iron casing with openings for the downtake, and is covered with cast-iron plates, secured by countersunk washers, making an even sectional floor, which can be readily removed to any desired point. The railing is constructed of cast posts and bar-iron rails, arranged so as to receive sheets of metal; thus making the fence either open or close, as required by the weather. The tunnel-head is fitted with Weimer's changer.

G. G. A.

Working Results of the Hydraulic-rod Pumping Engine at Saarbrücken. By H. Pfaehler.

(Zeitschrift für das Berg-, Hütten- und Salinenwesen, xxiii., pp. 60–72.)

This is a sequel to the Author's former Memoir on the same subject,[1] giving an account of the results obtained by the engine in continuous work. The speed has been increased from six revolutions per minute to twelve, without difficulty; and it is found that with a normal velocity of ten revolutions, perfect regularity and quiet movement are attained, the discharge from the rising pipe being permanent and continuous, a slight pulsation being observed in the stroke of the northern pump, which is ascribed to the fact, that the air pumps force air into the air vessel only on the lift of the opposite or southern pump, so that there is a little difference in the work done in the alternate strokes. In spite of the great pressure in the air vessels, there is no perceptible increase in temperature, owing to the great volume of water passing through, as compared with that of the air cushion. The temperature of the water in the sump was observed to be 51°·8 Fahr. (11° cent.) both in the sump and the rising pipe, at the same time the temperature of the air was 50° Fahr. in the engine-room underground, 44°·6 Fahr. in the shaft, and 26°·2 Fahr. at the surface.

In order to observe the working pressure upon the different parts of the engine five pressure gauges were used, placed as follows: one at the bottom of the rising pipe, and two on each of the rod tubes, one at the bottom, and the other at the surface below the point of attachment of the press pumps. The readings of these gauges have been plotted in the manner of indicator diagrams, and are given as illustrations. These diagrams are supposed to be correct within a margin of 1 or 2 atmospheres, and are the best that could be got in the absence of an indicator capable of working under pressures of 80 atmospheres and above. In the rising pipe, the pressure was very steady, and varied only between 26 and 28 atmospheres, the change being sensible only at the beginning and ending of the stroke. In the rod tubes underground, the variation in pressure was marked by extreme regularity and precision. When the pressure piston was making the return stroke, the gauge indicated uniformly 35 atmospheres, rose during the cataract pause with a vibratory movement to about 78 atmospheres, which remained the normal pressure to the end of the working stroke, when it fell with corresponding oscillation back to 35 atmospheres. There was little difference in the maximum pressure between the north and south rods, the latter indicating up to 80 atmospheres, this difference arising from the load not being

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xl., p. 294.

quite uniformly distributed between the two pumps. The oscillations of the gauges at the surface were somewhat greater, near the end of the return stroke, the pressure rose to about 15 atmospheres, increased during the cataract pause to 30 atmospheres, and on the commencement of the forcing action of the plunger suddenly rose to 50. This pressure was maintained regularly till close upon the end of the stroke, when it fell rapidly through 30, 15, 10 atmospheres to 0. In some cases, even a negative pressure was observed when, through loss of water in the tubes, a partial vacuum was formed, owing to the waste not being made up quickly enough by the auxiliary feed valves. The velocity of the column of water in the pressure tube was 7·6 feet, and in the rising pipes 3·6 feet per second.

In order to determine the work absorbed by the friction of the different parts of the machinery, two sets of observations were made—one with the engine running under full load at ten revolutions per minute, and the other with the pumps emptied of water, and the air and lifting pumps at the bottom detached. The results were as follows:—

	Atmospheres.
Working pressure at full load, average of both gauges	77·5
Deduct pressure due to hydrostatic head	27·0
Working pressure when loaded	50·5
Pressure with working load removed, average of gauges	39·7
Deduct hydrostatic head	27·0
Leaving pressure to overcome friction	12·7

Or in the proportion of $\frac{12 \cdot 7}{50 \cdot 5}$, or 0·25.

The gauges on the surface gave

	Atmospheres.
For the loaded engine	57·5
Do. unloaded engine	17·0

Or $\frac{17 \cdot 0}{57 \cdot 5} = 0 \cdot 29$. The work absorbed by friction may therefore be put at from 25 to 29 per cent. of the total power developed.

In the same way, the work done by the sump lifts which feed the system of main pumps, was found to be represented by a pressure of 4·5 atmospheres for the southern and 3·5 atmospheres for the northern pump, so that these lifts are balanced to within half an atmosphere. In the original Memoir the work of these lifts was estimated at from 5 to 6 atmospheres, but as actually less is required the Author considers it desirable to continue their use, in preference to adopting the dangerous experiment of lifting with the main pumps directly from the sump.

The measured discharge of the main pump was found to be 0·95 of the theoretical volume, a result which is attributed to the exact

closing of the valves. These have been modified from the original design. In the first instance, bell valves of brass, with inclined bearing faces, were used; but they soon became leaky, and were replaced by cast-iron double-beat valves, with square faces working against leather-packed seats, which have been found to act perfectly. The discharge of the bottom lifting pumps feeding the main engine cistern was 0·96 of the theoretical volume.

The effective work of the pumps, corrected by these experiments, making ten double strokes per minute, is 99·7 HP., say 100 HP. The corresponding work, taken from the indicator diagram of the steam-engine, with a mean pressure of 20 lbs. per square inch on the piston, is about 136 HP., which gives the combined duty $\frac{100}{136}$ $= 0\cdot73$ of the total power expended. The results as regards consumption of coal are not, however, so satisfactory. An experiment of eleven hours duration, gave a consumption of 22 lbs. per HP. per hour, which is about the same as that of the average consumption of the older kinds of condensing pumping engines in the district, but considerably above that of the newer forms of compound (Woolf) engines used for the same purpose. The Author, however, considers that this may be improved by the adoption of condensation and expansive working of steam; which, however, would require a modification of the details so as to allow the adoption of continuous rotatory motion, equalised by a fly-wheel. A method of improving the safety apparatus, so as to adapt this class of engine to more rapid working, is illustrated on an accompanying plate; as is also a method of arranging the lifts to draw the water at pleasure from the different working levels in the mine, by the use of a feed pipe common to all, in communication with the main pumps at the bottom of the shaft, which the Author considers would be preferable to the ordinary practice of making the lifts mutually dependent upon those above and below them.

H. B.

On the Winding Arrangements at the Styrian Iron-Company's Mines near Eisenerz in Styria. By M. JARITZ.

(Berg-und Hüttenmännisches Jahrbuch [Leoben], vol. xxiii., part 4, pp. 311–317, 1 pl.)

The deposits of spathic iron ore belonging to this company are situated at various points to the westward of the celebrated iron mountain of Eisenerz; they were first opened in 1872, when a system of railways for carrying the ores was laid out and completed in 1873.

The workings, which are in open-cast, are situated at four different levels, united together by self-acting inclines, the total difference of level being 2,016 feet from the top workings to

the railway station of Eisenerz, which is 2,190 feet above the sea-level. The total length of the lines, including the inclines, is 3,462 Vienna fathoms (about 4 miles). The longest of the inclines—the lowest one—is 300 fathoms (1,800 feet), which is laid at varying inclinations from 18° to 23°, according to the shape of the ground, in order to avoid the expense of the heavy cuttings or fillings which would have been required to make a line of uniform slope. At the changes of slope the lines are led into each other by an intermediate portion following a catenary curve. The horizontal portions are laid with steel rails of about 15 lbs. to the yard, which have a slight incline forward; so the work done by the horses drawing the wagons is about equal on either journey. One horse takes eight wagons, loaded with 2½ tons each, or 20 tons, outward, and draws the same number of empty trucks, weighing 6½ tons, back again. The inclines are laid with iron rails of 27 lbs. to the yard, the gauge of the way being 18 inches. The incline drums are conical, varying from 12 to 15 feet in diameter, one being loose on the shaft, with an adjustable coupling for varying the length of the winding rope. The shaft is made of Bessemer steel, and the seatings of cast iron, the remaining portions being of wood, the position of the works—on a steep wooded mountain-side—being such as to prevent the transport of heavy single pieces of machinery.

The wagons are lowered singly, being placed on a platform wagon running on the incline, so as to preserve the horizontal position. The gross load is about 4 tons for a single wagon-load of 2½ tons. The ropes are of steel, containing thirty-six wires (No. 12) in six strands, with hemp cores of a very high quality, made at Pribram, in Bohemia.

The average velocity of the descending load is 6 feet per second, which is maintained and controlled by a self-acting air break, similar to that already in use at Hüttenberg, in Carinthia. This consists of a three-armed fan with flat wooden blades at the ends, which is made to revolve by spur gearing from the main drum, the number of revolutions being increased in the proportion of 1 to 128. The resistance opposed by the air to the passage of the blades is very largely augmented by any increased velocity of rotation, such as would be produced by too great a speed in the descending load. The extra work produced by the gravitating mass under these conditions is rapidly absorbed in maintaining the higher velocity of the fan, so that the load is soon reduced to its normal travelling speed. On inclines of the character of those above described, where the slopes are broken, the speed of the fan should be calculated for the required mean velocity of the load and not for that due to the highest or lowest slope, so as to obviate the necessity of frequently using the lever breaks on the main drum, which, as a general rule, should only be handled on stopping or starting the load. The ore loaded into the wagons at the head of the inclines is delivered in the same wagons to the calcining kilns, which are placed alongside of the railway station at

Eisenerz without further handling, in order to obviate as much as possible the breaking of the lumps and the production of small ore in quantity.

The ore, when calcined, is sent away by railway to smelting furnaces at a distance (those of the company are at Zeltweg), where they are smelted for grey pig iron, which is converted into steel by the Bessemer process. The following are analyses (same vol., pp. 361–362) of pig metal and steel produced from these ores:—

	Charcoal Pig Iron.	Bessemer Steel.
	Per cent.	Per cent.
Carbon combined	0·410	0·120
Do. graphitic	2·860	..
Silicon	3·060	0·038
Phosphorus	0·103	0·075
Sulphur	0·023	0·037
Manganese	4·600	0·140

H. B.

On the Uchatius Steel Process at Wikmanshytte in Sweden.

By G. Arehn.

(Jern Kontorets Annaler, part 6, 1874, p. 368.)

In this process, steel is produced by fusing, in crucibles, a mixture of finely-divided cast iron with pure rich iron ore which has been previously roasted and reduced to powder. The pig iron, which is from one-third to one-fourth white (Swedish classification?), is granulated by running it when melted into a bucketed wheel which revolves at a high velocity in water. The ore is the best quality of calcined Bispberg magnetite, stamped fine and sifted, care being taken to select only the very richest. These preparations are necessary to obtain the complete mixture of the ore and metal, essential for the production of steel of good quality. If the materials are imperfectly mixed, the steel is too hard and blows in the ingot. The proportions of metal to ore in the charge of course differ according to the nature and temper of steel required. It is usual to keep the weight of metal constant, and only to vary that of the ore.

The melting furnaces are of the ordinary Sheffield pattern, coke being used as fuel. Blacklead pots from the Battersea works, holding ½ cwt., are made red hot before charging, and they are surrounded in the furnace with charcoal, which communicates the fire to the coke. The bottoms of old pots are used as covers, and stands are used to prevent the adhesion of the slag formed by the coke, to the bottom of the pot. If this should occur, the pot is so much cooled that it becomes impossible to command a melting heat. Two pots are placed in each furnace, which usually make three meltings per day.

As soon as the coke is well ignited the furnace is closed, for about an hour, in order to warm up the pots gradually; the draught is then increased by opening the damper at intervals of a quarter an hour until it is completely open. About three and a half hours are required for complete fusion of the charge. The pots usually stand six meltings, but the number is mainly dependent upon the quality of the coke, which must be of the very best description. With the milder qualities, of course only a smaller number can be got; thus, in making No. 6, containing from 0·3 per cent. to 0·45 per cent. of carbon, which requires from seven to eight hours for complete fusion, the pots can only be used once.

The consumption of coke is about 71·5 bushels daily, when two furnaces, making three heats each, are in use, corresponding to about 11·6 bushels per cwt. of steel. Formerly a somewhat smaller quantity was required, the increase being due to the use of air-channels in the brickwork for cooling the walls, which keep the furnace in shape, and allow them to run longer without repair than was previously the case. The interior lining of the melting furnace is made of a mixture of coarse and fine quartz, old pots ground to a powder, but free from dust, worked up with a little fire-clay in water. The lining lasts four days without repair; as soon as it begins to burn out, the holes are stopped with quartz bricks of about the same composition, air-dried and moulded to fit. The bottoms of old melting pots are also used for the same purpose.

The steel is classified according to numbers; No. 02 being the hardest, and No. 3 the softest, milder numbers being only produced exceptionally. The intermediate numbers are 03, 1, and 2.

No.	3	contains	from	0·7	to	0·85	per cent	of carbon.
„	2	„	„	0·85	„	0·95	„	„
„	1	„	„	0·95	„	1·10	„	„
„	03	„	„	1·10	„	1·20	„	„
„	02	„	„	1·20	„	1·30	„	„

No. 02 is used almost entirely for mill-stone dressing tools, but to a smaller extent for razors. Nos. 03 and 1 are tool steels. The latter is also a first-class die steel, while No. 3 is best adapted for stone-cutting tools of all kinds.

H. B.

On the Assortment and Marking of Bessemer Metal.

By RICHARD ÅKERMAN, Professor at the School of Mines, Stockholm.

(Jern Kontorets Annaler, part 2, 1875, p. 85.)

At present the double-marking system for Bessemer metal, viz., one for the carbon contents and the other for the forging test, seems to be the best obtainable. To indicate only the amount of

carbon appears insufficient; and it is desirable to denote in Tunner's method, by a Roman numeral, the forging test showing the physical properties of the metal. The only difficulty seems to be to get Tunner's scale for assortment according to forging adopted by all smiths, for which it would be necessary to gauge the physical properties by a scale determined by a metal free from all foreign substances other than carbon—as shown below; and also, in order to express the gradual softness or hardness of one class going over to another, to put an H for hard and an M for mild.

This double mode of marking would have the advantage of keeping the amount of carbon marked on the ingot, which is now generally done by all Swedish steel-makers, while, in addition, the other mark of physical properties would express its value as to softness, tenacity, brittleness, &c., arising from other impurities, such as phosphorus, silicon, and manganese.

The following example may serve as an illustration that silicon and manganese really influence the physical properties.

A piece of steel of 0·5 per cent. of carbon showed in a forging test a hardness of 0·65 to 0·70 per cent. of carbon. On analysing the same chemically it was found to contain 0·497 per cent. of silicon, 1·119 per cent. of manganese, and 0·035 per cent. of phosphorus—showing the cause of the brittleness from other sources than carbon.

Another example is found by Snelus.[1]

At Neuberg, a steel of 0·3 per cent. of carbon and 1 per cent. of silicon also showed great brittleness. This double-marking method proposed has therefore the advantage of indicating the exact amount of carbon and also the forging test, in Roman numerals; perhaps the most valuable to the consumer, who will be put on his guard in the use of a metal when these two figures in practice do not agree.

TUNNER'S SCALE.

				Per cent.		Per cent.
I.	Carbon	contents	between	1·65	and	1·40
II.	Do.	do.	do.	1·40	„	1·15
III.	Do.	do.	do.	1·15	„	0·90
IV.	Do.	do.	do.	0·90	„	0·65
V.	Do.	do.	do.	0·65	„	0·40
VI.	Do.	do.	do.	0·40	„	0·15
VII.	Do.	do.	do.	0·15	„	0·00

C. P. S.

[1] Iron and Steel Institute Journal, 1871, vol. i., p. 38.

On the Heating Arrangement for Eggertz's Coloration Test for Carbon in Steel and Iron. By H. A. Rosén.

(Jern Kontorets Annaler, part 4, 1875, p. 194, 1 pl.)

In these Annals for last year (p. 176), two principal conditions for obtaining exact results by this method have already been pointed out, viz.:

That the temperature should be exactly 176° Fahr. for the vessel in which the metal is dissolved, and that the solution must take place in the dark, for the least admittance of light would make the results unreliable.

An apparatus invented for this purpose consists of two cylindrical vessels, one inclosed in the other, with an intermediate space for water, which may be made to boil by applying a spirit lamp, and a third vessel, the lid of which has holes for all the test-tubes, which is made so much smaller that, when put into this first-named double vessel, air can circulate all round it and under it.

By this arrangement the test-tubes are kept in a more even temperature than if introduced direct into a boiling pan, and if the tubes, whether full or empty, always fill up the holes in the lid, the solution takes place at an even temperature of 176° Fahr., and in darkness.

This apparatus has been tried two months in the laboratory of the Motala Works, Sweden, with very good results. When the water in the external vessel is boiling, the heat given off to the inner vessel, through the intermediate air-chamber, is just sufficient to produce a temperature of 176° Fahr., which has been found sufficient to dissolve even the hardest steel in less than three hours; while the lid, well covered, prevents the entrance of light.

C. P. S.

On the Influence of Various Solutions upon the Rusting of Iron.

By Prof. August Wagner.

(Dingler's Polytechnisches Journal, Band 218, part 1, Oct. 1875, pp. 70–79.)

The Author discusses the influence of materials employed in boilers for the prevention of scale—as soda, lime, chloride of barium, etc.—upon the rusting of iron under water at the ordinary temperature, as well as corrosion of the iron, under the influence of heat. The results of his experiments at ordinary temperature are:—

Under distilled water saturated with carbonic acid and air, iron rusts nearly twice as much as under water containing air only. If, instead of distilled water, spring-water concentrated by

evaporation is used, an essentially different result is obtained; in this case iron rusts in water containing only air more strongly than in water containing air and carbonic acid. And it was generally found in these researches that iron under water containing air, but free from carbonic acid, with the presence of salts, except alkaline reagents, rusted much more quickly than in pure water. In water containing chloride of barium and chloride of calcium saturated with air free from carbonic acid, rusting is very energetic, but less striking with air and carbonic acid. Under water containing common salt and chloride of potassium, as well as under water containing ammonia, rusting in the presence of air and carbonic acid proceeds with the greatest energy. Under water containing chloride of magnesium rusting occurs with air and carbonic acid more strongly than in the presence of air free from carbonic acid. Addition of oil greatly prevents rust in water containing only air, as well as in water containing air and carbonic acid. Alkaline reagents, as lime and soda, entirely prevent the rusting of iron.

The corrosion of the iron under water at higher (boiling) temperature was estimated by loss of weight of the iron treated, with the following results:—

Under distilled water, the loss of weight—that is, the rusting of the iron—was very regular from week to week. In evaporated spring-water, leaving a residue, rusting takes place much more slowly than in pure water, and the loss of weight of the iron, after six weeks, was half that in distilled water. With water depositing carbonate of lime there was a marked protection from rusting. With evaporated spring-water, to which some chloride of barium was added, similar results were obtained, except that rusting proceeded regularly from week to week. Iron, after six weeks in barium and calcic chloride solutions, undoubtedly showed less loss of weight than in pure water; but the rusting in the first and second week was rapid, afterwards slower and very regular. Iron in common salt and potassic chloride solutions gave, undoubtedly, greater loss of weight than in pure water, and the loss is high at the commencement. The action of sea-water upon steam boilers, as containing common salt and chloride of potassium, is thus explained. With neutral solutions of chloride of magnesium the loss of iron at first is enormous, but lessens, and finally proceeds regularly. The greatest destruction of iron occurs with ammonia solutions. In alkaline reagents, as lime-water and soda solution, the iron is not changed in the least. Oil evaporated with spring-water greatly retards rusting; after the first week it ceases to be considerable, and gradually becomes very slight. The iron employed in these researches was sheet iron in strips; the results are tabulated in percentages. From these experiments the Author deduces the general principles that, both at ordinary temperature and at the boiling point the presence in water of such dissolved chlorine combinations as chloride of magnesium, of ammonium, sodium, barium, potassium, and lime, is very destructive to the iron so soon as air is admitted—a consideration important as affecting

the condition of boilers. It follows that addition of chloride of barium to feed water is likely to be injurious to the boiler. The evaporation of spring-water has less deteriorating influence than pure water, especially when by evaporation of the spring-water a thin preservative layer of carbonate of lime is thrown down upon the iron. Chloride of ammonium or sal-ammoniac solutions are to be carefully avoided. Addition of oil or fat to the feed water is proved by all the experiments not to be injurious to the iron, while it exercises a preservative influence against rust; but at higher temperatures than 212° Fahr. it is probable that the fat or oil has injurious effect. Addition of alkaline substances, such as lime and soda, to the feed water prevents, under all conditions, rusting of boiler plate. It would thus appear that these are the best boiler compositions that can be added to feed water.

P. H.

Calorimetric Study of the Carburets and Silicates of Iron and Manganese. By MM. Troost and Hautefeuille.

(Comptes-rendus de l'Académie des Sciences, 12th April, 1875, p. 964, and 9th August, 1875, p. 264.)

Although the employment of the bichloride of mercury gives a positive test of carbon in iron, it does not show whether the carbon is dissolved in the iron or combined with it. Using the calorimetric test employed by M. Berthelot in analogous researches, with M. Favre's calorimeter, and bichloride of mercury as the reagent, the conclusion was arrived at that if substances consisting of carbon and another element or elements disengage more units of heat than the element or elements, they are either explosives or solutions, and if less, they are chemical compounds. Guided by this consideration, the Authors have deduced from their experiments that carburets and silicates of iron belong to the category of explosive bodies, whereas carburets and silicates of manganese and ferro-manganese are stable compounds. The close relationship between the two metalloids carbon and silicon is shown by their action on iron, both appearing to dissolve in this metal.

E. B.

On the Transformation of Iron into Steel, by Cementation.

By M. Boussingault.

(Annales de Chimie et de Physique, June 1875, pp. 145–265.)

This is an elaborate investigation of the chemical changes that take place in a bar of wrought iron, when it is transformed by cementation into blister steel. The chief practical interest of the

Paper lies, however, in the detailed descriptions given of the methods of analysis adopted by the Author, and in the number of results of analyses quoted.

In the common process of cementation, the iron, in bars 60 to 65 millimètres (2·36 inches to 2·56 inches) broad, by 18 to 20 millimètres (0·709 inch to 0·787 inch) thick, is interstratified with powdered charcoal, and heated to redness, for some weeks, in large retorts or chambers built of brickwork, and of a capacity of 6·54 cubic yards each. A pair of these retorts, heated by one furnace, receive together a charge of 27 to 28 tons of bar iron, and 3½ tons of charcoal. In an experiment conducted at the steel works of Unieux (Loire), it was found, by drawing out trial bars, at intervals, from the retorts, that in an ordinary cementation process, lasting about five weeks, the iron was at a more or less bright red heat during fifteen days; of which time it was at or above a cherry red for about nine days, and at an orange red during seven days. The cemented bars, termed blister steel, differ much in their appearance and character from wrought iron. Their surface is covered with vesicles or blisters; and they are hard and brittle, crystalline in texture, and much lighter in colour than wrought iron. The elements present in the metal, in its two conditions, and of which the relative amounts contained in it before and after cementation show the changes effected in it by the process, are carbon, as combined carbon and as graphite, silicon, sulphur, phosphorus, manganese, and iron.

The methods of analysis preferred by M. Boussingault for the determination of the respective amounts of these constituents are as follows:—

For the determination of the carbon, the iron is first dissolved, by trituration at the ordinary temperature with about twenty times its weight of chloride of mercury (corrosive sublimate), in a moist state; the reaction being

$$2HgCl + Fe = Hg_2Cl + FeCl.$$

The whole of the carbon, both combined and graphitic, remains in admixture with the subchloride of mercury produced; and on driving this off, by heating to redness in a current of hydrogen, it is left behind, and its amount is determined by burning it, and either noting the direct loss of weight, or collecting and weighing the carbonic acid produced. The graphite and combined carbon may be distinguished, by effecting the combustion first in air, in which the latter, alone, burns, and completing it in a current of oxygen, to burn off the graphite.

Determination of Silicon.—The metal is completely oxidised, in a muffle, at a full cupelling heat; and the iron is then removed, as chloride, by heating to redness in a current of dry hydrochloric acid gas. The silica is left behind, perfectly white, and finely divided.

Determination of Sulphur.—The metal is dissolved in dilute

sulphuric acid, and the gas evolved from it is passed into an acid solution of nitrate of silver; the sulphide of silver formed is collected on a filter, washed, and burned; leaving a residue of metallic silver, of which 108 parts correspond to 16 parts of sulphur.

Determination of Phosphorus.—The phosphorus is first separated from the iron, by dissolving the metal in nitric acid, evaporating and calcining, and then fusing with carbonate of soda. The alkaline solution obtained, on boiling the fused mass in water, contains the whole of the phosphorus, while the oxide of iron remains undissolved. In this solution the phosphorus is determined either by precipitating it as phosphate of cerium, redissolving, throwing down again as phosphate of magnesium and ammonium, calcining and weighing; or by precipitating as phospho-molybdate of ammonium. In each case, care must be taken to avoid the error that may be caused by the presence of silica in the solutions.

Determination of Manganese.—When the proportion of manganese present amounts to 2 or 3 per cent. very good results are obtained through the ordinary method of determining it, by first separating the iron, from a solution of the metal to be analysed, by acetate of sodium, and then throwing down the manganese from the filtrate, by a solution of hypochlorite of sodium, or of bromine; and even when the quantity of manganese is very small, as in most specimens of wrought iron and steel, accurate results may still be obtained by it, if carried out with care, and if the several reagents employed are used in measured quantities. Minute traces of manganese, not exceeding 0·2 or 0·3 per cent., may also be determined very readily, and with considerable accuracy, by a method based on a reaction pointed out by Rose—the production of an intense purple coloration on heating a solution of a salt of manganese with nitric acid and binoxide of lead. The amount of manganese present is determined by adding, drop by drop, to a measured quantity of the purple liquid, a standard solution of subnitrate of mercury, until the colour is destroyed. The presence of iron, in the solution, does not at all affect the accuracy of the result.

Determination of Iron.—The method that M. Boussingault prefers, for the determination of iron, is the well-known volumetric process of Margueritte; the addition to the solution of a protosalt of iron of a standard solution of permanganate of potassium, until a permanent pink coloration is produced. Before, however, proceeding to determine, by this method, the percentage of iron in a sample of grey or mottled cast iron, containing at once combined carbon and graphité, the carbon should first be burned off, leaving the iron as oxide, and the oxide should be reduced again to metal, by hydrogen; as on dissolving the cast iron, directly, in acid, in the ordinary way, the graphitic residue left retains some hydrocarbon, which reduces a small quantity of the permanganate, and so makes the apparent percentage of iron too great; the error thus caused may amount to 0·10 or 0·15 per cent. Copper or arsenic, if present in the metal, affects also the accuracy of the determination, and must be first removed: the presence of even minute traces of

copper may be readily detected, by precipitating the iron in the usual way by ammonia, neutralising a portion of the filtrate, and adding to it a drop of a solution of ferrocyanide of potassium: this causes a brown precipitate of ferrocyanide of copper, if any copper is present. For standardising the solution of permanganate, chemically pure iron, made by the process of M. Caron, is most suitable: this is made by reducing the calcined oxalate by hydrogen, and subsequently fusing the reduced metal, still in an atmosphere of hydrogen, in the porcelain tube in which it was reduced. If such pure iron is not at hand, other iron, of known composition, or purified sulphate of iron, may be used.

M. Boussingault proceeds next to discuss, at considerable length, the question of the higher limit of the carburation of pure iron,—*i.e.*, of iron free, or nearly free, from manganese, silicon, sulphur, phosphorus, &c.,—and arrives at the conclusion that the formula Fe_8C, corresponding to

Iron	95·90
Carbon	4·10

represents the probable composition of the highest simple carburet of iron; any carbon contained in the metal, in excess of this amount, being in the form of mechanically intermixed graphite.

The concluding section of the Paper deals with the cementation process itself, and the changes that are effected by it in the composition and structure of the metal. The cemented bars are generally more or less blistered, and are invariably found to be coated with an extremely thin film of finely divided graphite, soiling the fingers like plumbago. The precise cause of the blisters has not been determined. One view, commonly held, is that they are due to the presence, in the bars, of small quantities of cinder (basic silicate of iron), which is reduced in the process of cementation, giving off the contained oxygen as carbonic oxide, which produces the blisters. Another view, put forward by M. H. Saint-Claire Deville, is that just as a flattened wrought-iron tube, closed at the ends, and heated to welding in a reheating furnace, absorbs hydrogen, by endosmose from the flame, and becomes swelled out and round again, so in the cementation process, the numerous bad welds throughout the iron bars, being equivalent in effect to portions of such flattened tubes, become blown out in the same way, into blisters, by endosmose of hydrogen, contained in the charcoal, or produced by the decomposition of water vapour. The maximum amount of carbon that iron is capable of taking up, in a true cementation process, that is when heated in charcoal without fusion, appears to be about 2 to 2·5 per cent. In the manufacture of ordinary commercial blister steel, the amount of carbon taken up does not generally exceed 1·5 per cent. Other alterations effected by cementation in the composition of the metal are: the gain of traces of phosphorus and silicon, from the brasque; the loss of a minute quantity of the iron, probably carried off as chloride; and, lastly, the elimination of more than half the amount

of sulphur contained in the bar iron. This elimination of sulphur, in the process of cementation, is very remarkable, and tends to account for the old and commonly received opinion that cemented bar, melted in crucibles, makes the best quality of tool steel. The proportion of sulphur contained in white cast iron is also diminished by cementing it: in some experiments made by the Author, the percentage of sulphur was found to be reduced to one-fifth.

M. Boussingault sums up the results of his examinations of different varieties of crucible cast steel as follows:—Those varieties of cast steel that are considered the best, consist essentially of nothing but iron and carbon. In proportion as they become higher in quality the sulphur is found to diminish and to disappear. They are generally free from phosphorus; and manganese and silicon enter into their composition only in minute quantities, rarely exceeding 0·1 per cent.

W. H.

Rosset's Improvements in the Manufacture of Bronze Guns.[1]

(Revue d'Artillerie, May 1875, pp. 134–148.)

This is a résumé of portions of the standard work "*Esperienze Meccaniche sulla Resistenza dei principali Metalli da bocche da fuoco,*" by Colonel G. Rosset, of the Italian Artillery, Director of the foundry of Turin.

The bronze guns now in service in Italy contain 11 to 12 parts of tin to 100 of copper, and from 8 to 13 parts of tin per 100 of copper in other countries. The composition of the alloy is, however, far from being uniform throughout the mass of any one gun, as during the slow cooling of the liquid bronze, in the sand moulds commonly used, portions of harder white alloys, rich in tin, separate here and there, by liquation, and show as whitish spots, on the cut surface of the metal or on the fracture. The distribution of these spots of tin in the mass does not appear to follow any definite law.

On account of the want of uniformity in the composition of existing bronze guns, the series of test bars prepared by Colonel Rosset for the determination of the mechanical properties of bronze containing different proportions of tin, and cooled slowly or rapidly, were cut from ingots cast specially for the purpose.

Four ingots, containing respectively 9, 11, 13, and 15 parts of tin in 100 parts of the alloy (not in 100 parts of copper), were cast in sand moulds, and thus cooled slowly; and four ingots containing 7, 9, 11, and 13 parts of tin in 100 of the alloy were cooled rapidly, by casting them in heavy cast-iron moulds or chills, twice the weight

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[1] The following work may be consulted on this subject: "Reports of Experiments on the Strength and other properties of Metals for Cannon." By Officers of the Ordnance Department. Philadelphia, 1856.

of the ingot. The test bars cut from these eight ingots showed that the metal cooled rapidly was in each case of greater specific gravity, more compact, more elastic, stronger, more ductile, and harder, than that of the same composition cooled slowly, and on the cut or broken surface, the bars of metal cooled rapidly showed none of the whitish spots of tin found in bronze slowly cooled. The hardness, elasticity, and homogeneity of the bronze increased, also, with each increase in the proportion of tin. The alloy best suited for cannon appeared to be that containing between 10·5 and 11·5 of tin in 100 of the alloy, equivalent to 11·7 to 13 of tin per 100 of copper. The test bars, of bronze of this composition, showed an increase of 30 per cent., in the tenacity of the metal, by cooling it rapidly in an iron mould.

Further experiments on the metal of several field-guns of 2·9 inches bore, and of a howitzer of 8·66 inches, cast in iron moulds lined with a wash of refractory material $\frac{1}{25}$ inch thick, fully confirmed the conclusions drawn from these preliminary trials; the bronze being in every way superior to that of guns cast in sand moulds in the ordinary way.

The following are some of the comparative results:—

Test Pieces 7·87 inches (200 millimètres) in length by 0·98 inch (25 millimètres) in diameter.	Guns cast in Sand Moulds.		Guns cast in Cast-iron Chills.	
	Kilogrammes per Square Millimètre.	Tons per Square Inch.	Kilogrammes per Square Millimètre.	Tons per Square Inch.
Breaking strength	17·8	11·3	27·8	17·65
Limit of elasticity	8·83	5·6	10·8	6·75
	Per cent.		Per cent.	
Ratio of section at fracture to original section	87·3		84·0	
Elongation per cent. (to limit of elasticity)	0·087		0·093	
Density	8·73		8·74	

From a few experiments, made in 1871 and 1872, Colonel Rosset considers that phosphorus bronze presents no practical advantages, for bronze guns, over ordinary bronze, cast, as he recommends, in chills.

W. H.

On the Manufacture of Bronze Guns.

By Colonel A. S. Lavroff, of the Russian Artillery.

(Revue d'Artillerie, July 1875, pp. 273–291.)

If a piece of ordinary gun-metal, containing about 10 per cent. of tin, is strongly heated, globules of a fusible white alloy, rich in

tin, appear on its surface; and if there is a hole in the metal, the walls of this become equally covered with the same fusible alloy, which may even entirely fill the cavity, producing a spot of tin. A similar phenomenon takes place, when a hollow or a bubble has formed, during the solidification of a cast ingot: the hollow becomes filled up, in some cases, with a fusible white alloy, which sweats out from the surrounding metal. Spots of tin, in a bronze casting, correspond, then, to hollows formed during the solidification of the metal, which become filled up, under certain conditions, by a white alloy rich in tin.

The Author has been led, by this consideration, to the endeavour to cast bronze guns perfectly compact, in order to obtain a homogeneous metal, free from flaws or variations in composition. With this object, he has adopted the plan of casting them vertically, with the muzzles downwards, and in cast-iron moulds or chills; the head only, which is cut off in finishing the gun, being cast in a portion of the mould lined with sand. In this way, the metal is cooled rapidly; and the solidification, commencing at the narrowest part, the muzzle, proceeds regularly upwards; liquid metal from the upper part of the mould, and from the head, being at hand, to feed each part of the casting as it contracts, and so to prevent the formation of hollow spaces. Lastly, the metal of the upper part of the casting, the breech of the gun, is condensed, as it solidifies, by hydraulic pressure.

All the guns cast in this way have proved entirely free from blow-holes, and from any spots of tin, except a few minute specks towards the centre of the ingot; and the strength and toughness of the metal are remarkably increased: the breaking strength, in some specimens, reaching 31·5 tons per square inch (49·9 kilogrammes per square millimètre), and the ultimate stretching being 44 per cent.[1] A 9-pounder gun, thus cast, has stood successfully one hundred charges, fired with 4·5 lbs. of powder, producing a pressure in the chamber equal to between 2,500 and 2,800 atmospheres, while the best guns of similar dimensions on the old system gave way with a 4-lb. charge. An 8-inch mortar has been proved by three hundred charges, with 17 lbs. of prismatic powder, producing a pressure of 1,300 atmospheres, and one hundred charges with 15·3 lbs. of ordinary powder, developing a pressure of 2,000 atmospheres.

These guns, though much superior to those cast in the ordinary way, still, however, presented certain defects; the first being a slight want of homogeneity in the middle of the ingots, to remedy which the proportion of tin has been reduced to 8 per cent., and the second being that the guns, though harder than those cast of the same bronze, in the ordinary way, still showed a sensible enlargement of the bore, after firing, caused by the pressure of the powder gases. In a 9-pounder gun, the enlargement of the bore,

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[1] The form and dimensions of the test pieces are not stated.

towards the breech, produced by a charge of gunpowder developing a pressure of 2,000 atmospheres, amounts to 5 or 6 hundredths of an inch. To prevent this bulging, and at the same time to harden the inner surface of the bore, the Author has carried out, very successfully, the plan of boring the guns to a diameter about 4 per cent. smaller than the intended calibres when finished, and enlarging the bore to the required size by forcing through it, by hydraulic pressure, a series of three or four steel mandrils, each a little larger than the preceding. The effect of this treatment is that the bore is expanded, uniformly, from end to end, to such an extent that, on firing, it is not bulged at all; and the inner surface is at the same time made nearly as hard as steel, so that it is less worn by the friction of the projectile and of the powder gases.

The state of permanent strain induced in the metal of a gun treated in this way, resembles that in a wrought-iron gun built up of concentric hoops or coils; the inner layers being in compression and the outside in tension. The pressure required to enlarge the bore of a 4-pounder gun, of 3·42 inches calibre, exceeds 64 tons; the diameters of the mandrils forced through, successively, to open out the bore, from 3·3 inches to the finished size, being 3·35, 3·39, 3·42, and 3·435.

The Author's system of making bronze guns is similar in many points to that of General Uchatius. In what Uchatius calls 'steel bronze,' he also reduces the proportion of tin to 8 per cent., he casts the gun in metal chills, with the upper part or 'head' in sand, and he enlarges the bore by forcing through it a series of steel mandrils. The principal differences between his mode of proceeding and that of the Author are that he casts the guns hollow, on a core, instead of boring them out from the solid; and that he enlarges the bore, by mandrils, to the extent of 8 per cent. of its diameter, instead of only 4 per cent. The effect of casting the guns hollow is to produce castings less sound and strong than if they were cast solid; as, during the cooling of the metal, the still liquid bronze in the upper part cannot flow down so freely, as one part after another contracts in solidifying. The effect of this on the strength of the metal is shown by the following table, which gives the properties of bars of Uchatius bronze, cut from different parts of a finished gun:—

Specimen cut from	Breaking Strength.		Limit of Elasticity.		Elongation.
	Kilogrammes per Square Millimètre.	Tons per Square Inch.	Kilogrammes per Square Millimètre.	Tons per Square Inch.	Per cent.
The outer surface .	33	20·9	8	5·0	43
The middle of the thickness . . .	29	18·4	7	4·5	27
Close to the bore .	48·75	30·9	18	11·4	3·2

The metal close to the bore, having been strongly compressed, has of course greater tensile strength, and stretches less, than that

near the outer surface; but the metal from the middle of the thickness is much inferior, in this Uchatius gun, to that near the outside, both in tensile strength and in percentage of stretching.

It is probable that the excessive enlargement of the bore, adopted by General Uchatius, is also injurious; by too much reducing the ductility of the metal, and so rendering the surface of the bore more liable to crack.

W. H.

On the Velocity with which Ignition spreads in a Mixture of Air and Fire-damp, and on the Theory of Safety Lamps.

By Prof. M. E. Mallard.

(Annales des Mines, vol vii., pp. 355–381.)

The minimum temperature at which gaseous elements will combine may be called that of *ignition* (t). If a volume of the mixture be inclosed in a perfectly non-conducting vessel it will possess a certain temperature of *combustion* (T). The velocity with which combustion proceeds is the *velocity of ignition*. By assuming in a non-conducting tube two sections indefinitely close, the one heating the other in an indefinitely short interval of time, the variation of temperature being a function of the space and also of the time, and the velocity of ignition being the quotient of these, then

$$\frac{dl}{d\tau} = V = \frac{u}{k} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where u is the rate of variation of temperature between the sections, and by the law of Newton

$$u = a(T - t) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

a being a co-efficient dependent on the nature of the mixture.

Assuming a law similar to that of metallic conductivity, k is a constant, defined as

$$k = a(t - \theta) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where a depends on the nature of the mixture and on the form and nature of the containing vessel; and θ is the original temperature of the gaseous mixture.

Continuing the comparison

$$a = \sqrt{\frac{\gamma p}{c s}},$$

p and s being the perimeter and section of the tube, γ depending on its cooling, and c being the reciprocal of gaseous conductivity.

From 1, 2, and 3, it follows that

$$V = \frac{a\,T - t}{a\,t - \theta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

and

$$V = a\sqrt{\frac{c}{\gamma}}\sqrt{\frac{p}{s}}\,\frac{T - t}{t - \theta};$$

in gases similar or approximately similar in nature

$$V \text{ varies as } \frac{T - t}{t - \theta}.$$

t, the minimum temperature of ignition, is easily obtained; T, on the contrary, is not easily determined, and St.-Claire Deville and Debruy, and M. Bunsen have not been satisfied with their own determinations. The combustion temperature (T), however, is a function of (V), of which experimental determinations are given farther on.

The formula (4) shows that after a gaseous mixture has been ignited it will not burn unless $T > t$; then only can it explode. This is evident *à priori*, because otherwise heat is absorbed, and combustion can only go on by an external source supplying the heat so absorbed. On V depends the nature of the explosion or combustion: being similar to a slow powder when it is small, and to a quick powder when it is large.

From the same formula it is evident that increasing the temperature of a gaseous mixture will hasten explosion; T being thus increased. It also explains the fact stated by M. Bunsen, that a mixture inexplosive in the air may be exploded in a closed tube.

The Author knows of no experiments on the velocity of ignition but those of MM. Schlœsing and Demondésir, and some indicated by M. Bunsen in his memoir on temperatures of combustion. As some time may elapse before his experiments can be completed, he gives the results hitherto obtained. In his method of procedure he followed these experimentalists, igniting a detonating mixture having a certain known velocity of translation, which when the ignited section remained steady showed that the velocity of ignition equalled that of translation. A suitable apparatus was employed, and is described, the velocity of translation being taken when the hinder portion of the flame was on both sides of a thin partition with a small central hole. The mean of these two velocities is the value of V, which for fire-damp and air is given in a table, and shown on a curve. From these it appears that the maximum velocity of ignition is 22 inches per second, corresponding to a proportion of 0·108 of fire-damp in a volume of the mixture. A very small diminution or increase of this ratio causes a rapid variation in the velocity of ignition; with a quantity of fire-damp below

0·077 and above 0·145 in a volume of the mixture, it is neither inflammable nor explosive. The proportion giving a maximum velocity of ignition does not altogether correspond with that wherein the fire-damp finds in the oxygen of the air the exact quantity necessary for combustion. The Author has no doubt that this is due to what M. Deville calls the *tension of dissociation*, which limits the combination of gaseous mixtures. This result agrees with the experiments of Davy, and gives the most explosive mixture as between the limits of greatest volume and greatest velocity 0·148 and 0·122 per volume of air. The same experiments were made with illuminating gas. The maximum velocity of ignition was found to be 3·34 feet per second, corresponding to a proportion of 0·167 of gas per volume of mixture. Below 0·117 and above 0·235 the mixture was not inflammable, and a variation of 0·01 in the proportion of gas suffices to render perfectly inert a mixture eminently explosive. To this circumstance many dangerous accidents are doubtless due; a slight variation in the quantity of gas disengaged by the coal, or in the velocity of the current of air in the mines, being sufficient to cause such an effect, particularly where ventilation varies with the barometer and thermometer. The Author considers that fire-damp explosions depend on the speed of ignition of the mixture, on the velocity with which the gas expands, and on the rapidity and direction of currents in the gallery. If the current has a velocity greater than 2 feet per second, the direction of ignition is that of the current.

The Author next propounds a theory on safety lamps, and deduces from his formulæ that, with an equal velocity of translation, wire gauze which will stop the flame of fire-damp will allow that of illuminating gas to pass, a result which agrees with experiment; and, further, that if fire-damp is projected on wire-gauze with a velocity of from 6·6 feet to 9·8 feet per second, it will be sufficient to allow it to pass through its meshes. He next proceeds to a consideration of the Davy lamp and the safety lamp of the Mueseler type, in which the flame is fed by a current of air passing through an annular wire gauze, fixed in the upper part of the glass cylinder, the products of combustion passing away by a central cone. In the Davy lamp, with less than 0·08 of fire-damp, the flame of the wick becomes fuliginous and lengthens; with 0·08 there is a blue flame, the wick having its ordinary length; at 0·10 the wick becomes invisible, and a blue flame fills the lamp. These effects are shown to depend on the velocity of ignition. In the Mueseler lamp, with 0·067 of fire-damp the flame becomes dim, with 0·083 it diminishes considerably both in height and brightness, and an almost complete extinction of the flame takes place periodically; with 0·10 a bluish flame rises to the gauze ring and then goes out; with 0·125 there is a complete extinction. When the flame of the wick was surrounded by very thin wire gauze, extending as high as the central cone, the ascending and descending currents were better

separated, the flame was prevented from rising in the descending current, and no oscillation of flame occured. The Author considers these phenomena to be also due to the velocity of ignition. He concludes by stating that the Mueseler lamp is superior to the Davy, but that the former is far from perfect, and that a study of existing types is useful in drawing attention to the direction in which improvement may be effected.

E. B.

On the Protection of Inflammable Materials against Fire.

(Oest. Zeitschrift für Berg- und Hüttenwesen, No. 42, pp. 442–446.)

The methods proposed by Bergrath Patera for the protection of easily inflammable materials, such as clothing, linen, timber, &c., have been recently experimented upon at Vienna in the laboratory of the metallurgical department of the Government with very favourable results. The editor of the journal directs attention to previous articles on this subject published in 1871.

The compositions recommended for this purpose are:—

1. A mixture of borax and sulphate of magnesia, prepared by dissolving 3 parts of borax and 2¼ parts of sulphate of magnesia in 20 parts of water. The action of this solution depends upon the formation around the fibres of articles steeped in it of a coating of borate of magnesia insoluble both in cold and hot water, which hinders the development of combustible gases and the propagation of flame through the protected substance.

2. An equally good protective is furnished by a mixture of sulphate of ammonia and gypsum. The latter appears to form a double salt with the ammonia sulphate, which is nearly, if not quite, free from the unpleasant properties of the ammonia sulphate when used alone. The protection is not only due to the mass coating the fibres, but to the ammoniacal gas given off, which acts directly in extinguishing flame. A mixture of 1 part of sulphate of ammonia with 2 of gypsum in a concentrated solution of salt, when simply laid on timber roofs or buildings, forms a useful safeguard, without actually making them fireproof, as it renders the wood more difficult of ignition, and practically incombustible when the action of external flame is removed. As these properties of the solution are gradually removed by exposure to water, it has been tried to waterproof it by a coat of oil-paint, linseed oil, or tar, which appear to have but little effect in diminishing the fire-resisting qualities of the material. Experiments on a large scale with this mixture at the salt-works at Ebensee, in Tyrol, have led to its recommendation for adoption in the other salt-works belonging to the Austrian Government.

H. B.

On Nitro-glycerine and Dynamite.[1] By A. Brüll.

(Mémoires de la Société des Ingénieurs Civils, April–June, 1865, pp. 391–485.)

Explosive substances are those which are able, by internal chemical action, to evolve a large quantity of gas at a high temperature in a very short space of time. Part of the heat developed in an explosion is expended in heating the surrounding bodies; part is absorbed by the expanding gases, and the rest is converted into mechanical work. Although the amount of heat an explosive can develop is not a measure of its useful work, yet M. Berthelot has shown that in special cases, such as the power of projection, it may serve as a standard of comparison. For the blasting effects, however, of different explosives, the heat developed in explosion must be multiplied by the volume, at standard temperature and pressure, of the gas produced, as the effect depends upon the maximum pressure produced, which has not yet been experimentally ascertained for most explosives. The heat evolved can be estimated by assuming it to be the sum of the quantities of heat produced by the formation from their elements of the products of combustion, less those produced by the formation from their elements of the explosive mixture. The result calculated by this method for gunpowder agrees approximately with that obtained from its explosion, by MM. Bunsen and Schischkoff, by means of a calorimeter. The heat evolved in the explosion of nitro-glycerine and dynamite has been calculated by the same method, and their effects compared with that of gunpowder, as shown in the following table:—

Explosive.	Composition.		Heat Evolved in Explosion.	Volume of Gas Produced per lb. of Explosive.	Product indicating measure of Blasting Effect.
			Thermal units.	Cubic feet.	
Gunpowder .	Potassium nitrate . . Sulphur . . . . . . Charcoal	74·70 12·45 12·25	1,093	3·61	3,945
Powder made with sodium nitrate . .	Sodium nitrate . . . . Sulphur . . . . . . Charcoal	79·6 11·3 9·1	1,350	3·97	5,359
Nitro-glycerine	$C_3H_5O_3\,3(NO_2)$ . .		2,372	11·41	27,064
Dynamite, No. 1	Nitro-glycerine . . . . Silica.	75 25	1,780	8·56	15,236
Dynamite, No. 3	Sodium nitrate . . . . Charcoal . . . . . Nitro-glycerine . . .	70 10 20	1,328	5·93	7,875

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxiv., p. 327 *et seq.*

The unit of weight taken in the above table is 1 lb., and it is evident that, for equal weights, the blasting force of powder is far inferior to that of nitro-glycerine and dynamite. In the explosion of powder and dynamite No. 3, intermediate products are formed, which are again decomposed with evolution of heat, so that the theoretical number of thermal units deduced from the ultimate products are too large in these cases; but this prolonged evolution of heat, though diminishing the blasting effects, adds to the projecting power.

Nitro-glycerine, discovered by M. Sobrero in 1847, is formed by the action of nitric acid on glycerine;

$$\underset{\text{Nitric acid.}}{3(HNO_3)} + \underset{\text{Glycerine.}}{C_3H_8O_3} = \underset{\text{Nitro-glycerine.}}{C_3H_5O_3\ 3(NO_2)} + \underset{\text{Water.}}{3H_2O};$$

concentrated sulphuric acid is added to remove the water formed, and the heat evolved has to be kept down to prevent the decomposition of the nitro-glycerine. When heated rapidly to 360° (Fahr.) it explodes;

$$2\{C_3H_5O_3\ 3(NO_2)\} = 6CO_2 + 5H_2O + 6N + O;$$

but when exposed to a flame it decomposes gently. It is stable, when pure, at ordinary temperatures: but, though poisonous, habitual contact with it diminishes the hurtful effects. Being only capable of partial explosion by ordinary methods, nitro-glycerine continued useless till M. Nobel discovered the method of complete explosion with certainty by detonating mercury placed in a strong cap in contact with it. The catastrophes resulting from its accidental explosion led to its abandonment; but M. Nobel having discovered, in 1861, that by mixing with kieselguhr, or other absorbent substances, it became safe for transport and use, and retained in a great measure its blasting powers, this mixture called dynamite has taken its place. Dynamite No. 1 contains ordinarily 75 per cent. of nitro-glycerine; on exposure to fire, when unconfined and in moderate quantities, it burns, but does not explode; and when confined, the force of the explosion varies with the strength of the envelope. It freezes at 46°, and in that state is less readily exploded. The perfect explosion of dynamite generates no noxious gases, but its burning does. Moderate shocks do not affect it; cases have been filled with it, and let fall on rocks from a height of 82 feet; and cartridges containing it have been crushed by stones, weighing nearly 2 cwt., falling 100 feet, without explosion occurring. MM. Bolley, Kundt and Pestalozzi projected copper cases of various thicknesses, 2 inches long and $\frac{3}{8}$ inch diameter, containing 0·12 oz. of dynamite, from an air-gun against a rock; the dynamite in the light cases, having a greater velocity and less protection from the shock, exploded; but that in the thick cases did not. Mr. Abel has exploded a cartridge of dynamite weighing $2\frac{3}{4}$ ozs., at one end of a wrought iron tube, 5 feet long and 1·22 inch internal diameter, by means of the explosion of a similar cartridge at the other end; and, from a series of recent experiments, he has found that the distance through which transmission can be effected

depends upon the nature and quantity of the initial substance, and upon the nature of the recipient, but not upon its quantity; also upon the relative diameters of the cartridges and of the tube, and on the continuity and smoothness of the tube. The velocity of transmission along a continuous train of dynamite is about 20,000 feet per second; but it is reduced to 6,200 feet when the cylinders of dynamite are placed ½ inch apart; and, from various experiments, it appears that the transmission of explosion from one charge of dynamite to a separate one, varies with the distance between them, with the amount of the initial charge, and with the nature of the packing of the recipient charge.

The Author refers to the works of Captain Fritsch and M. Barbe for full information as to the applicability of dynamite to military operations, and gives quotations from them which show that, for making breaches effectually and rapidly, without mining, with small charges and little exposure; for blowing up bridges, bringing down trees, fracturing cannon, and for other destructive works, dynamite is of the greatest value. For shells it has hitherto proved unsuitable, as it shatters them too completely.

M. Brüll points out, by numerous extracts from reports, that the principal value of dynamite consists in the great economy in time and labour its use has effected on various works, owing to its great blasting power with a comparatively small bore-hole; so that, though more expensive than blasting powder, it has caused a saving of from 20 to 40 per cent. on the cost of blasting, and that the same work can be executed in half the time. Its value is most marked in damp places and with hard rocks. M. Trauzl, in his report to the Austrian Government upon dynamite, comparing it with blasting powder, remarks that its preparation is simpler and quicker; that it is less dangerous both for transmission and use; that its effect is, according to circumstances, from twice to ten times as great as that of powder, and is specially advantageous where the charge cannot be confined; that for tunnelling and quarrying it will quite supersede powder; that for shafts and wells the economy in boring is in money from 20 to 40 per cent., and in time, from 40 to 70 per cent., and is specially marked in works under water; and, lastly, that the gases resulting from its proper explosion are less injurious than those generated by that of powder. In Austria the annual consumption of dynamite exceeds 500 tons; but in France, till March 1875, its manufacture and sale were prohibited.

L. V. H.

On Compressed Charges of Gunpowder.

(Revue d'Artillerie, May 1875, pp. 108–121.)

When a charge of ordinary cannon powder is fired in the bore of a gun, the very high initial pressure of the explosion is apt to strain or burst the piece, as nearly the whole of the charge becomes

ignited before the shot has acquired any great velocity. This intense pressure, on the interior of the bore, is especially injurious in the case of bronze guns, as the metal of these is comparatively soft and readily strained. The initial pressure of the fired gunpowder is moderated, either by forming it into compressed charges, or, more commonly, by moulding it into pellets, or prismatic blocks, of such size that they may just be completely burned by the time the shot reaches the muzzle. Pellet powder is made by compressing the ground and mixed materials, at once, in a slightly moist state, into pellets or blocks of the required size, instead of forming the mass into press-cake, to be subsequently dried and broken up into grains. Compressed charges, on the other hand, are made by compressing ordinary dry cannon powder, already granulated, into the form of rings, or short hollow cylinders, loosely fitting the bore of the gun, and of which five or more, placed together in a cartridge-case, make up the charge. The grains of powder, in such a charge, are not destroyed, but only squeezed together, so as to form a coherent mass; and thus, when it is fired, though the rate of combustion is at first comparatively slow, and the pressure moderate, as the blocks expose but a small surface for ignition, the grains soon fall apart, and then the powder burns as quickly as if it had been filled into the cartridge case in its loose, uncompressed, state. The initial pressure, and with it the wear of the bore, are thus kept down, while, at the same time, a high velocity is communicated to the projectile.

W. H.

Ventilation and Air-cooling Machine. By Ph. Delahaye.

(Revue Industrielle, September 8, 1875, pp. 337–339.)

The apparatus described is more particularly applicable to halls, theatres, hospitals, &c., for washing, purifying and cooling the air in summer; it is also applicable to spinning mills to overcome the dryness of the atmosphere which is so objectionable.

The apparatus consists essentially of a rectangular case, divided nearly horizontally by a metallic plate partition perforated with many small holes, and inclined at a slight angle, which inclination is made adjustable. At the higher end of this partition is a trough. from which a constant supply of fresh water flows in a stream over the whole surface of the perforated partition. This, and the angle of inclination of the partition, is regulated in accordance with the quantity and desired reduction in the temperature of the air to be cooled and cleansed. A fan of sufficient capacity is attached to and delivers the air into the case at one side and beneath the partition, to escape from whence, into the exit pipe at the top of the case, it passes through the small holes in, and the constantly

renewed layer of water upon, the partition plate, and is thus cleansed and lowered in temperature preferably to about 5° above that of the water.

During some experiments in July 1874, when the fan was driven, and water pumped from a well, by a small vertical engine, the apparatus cleansed about 35,300 cubic feet of air per hour, lowering it in temperature from 70° to 56° Fahr., and using about 264 gallons of water. The dimensions of the perforated partition, which are about equal to the horizontal dimensions of the case, were in this experiment about 3·28 feet by 2·6 feet, the holes cutting away about one-ninth of its surface. For the supply of about 883,000 cubic feet of cleansed and cooled air per hour, an engine of about 8 HP. and from 4,400 to 5,000 gallons of water per hour would be required. The apparatus is considered especially valuable where large quantities of air have to be cleansed and lowered through about 10° or 15° in temperature; its supply may be varied within very wide ranges, say from 1,000 to 20,000 cubic feet of air per hour from one size of apparatus. It is essential to the working of the apparatus that there should be a supply of well water at a temperature of about 53°.

W. W. B.

Purification of Coal Gas by Oxide of Iron.
By M. Mallet.

(Comptes-rendus de la Société Technique de l'Industrie du Gaz, May 1875, pp. 10-15.)

The material generally used for the purification of coal gas consists of a mixture of hydrate of sesquioxide of iron with sulphate of lime. It is known that by the action of foul gas, sulphuretted hydrogen is brought into contact with the oxide, and turns it into sulphide of iron; sulphur and water are produced at the same time. On the other hand, by acting upon the sulphate of lime, the carbonate of ammonia contained in foul gas produces, by mutual decomposition, sulphate of ammonia and carbonate of lime. It is also well known that when exposed to the air, the foul material is revivified and oxide of iron again generated. This is produced by the action of oxygen upon the sulphide of iron. Chemists differ as to the way in which such action takes place.

There are two opinions on this point. Some argue that the sulphide of iron is first converted into sulphate, and hence into oxide; others, that the iron unites with oxygen and parts from its sulphur. To decide the question, M. Mallet has undertaken the following experiment:—

A solution of chloride of iron is prepared by pouring into a solution of common sulphate of iron a solution of chloride of barium. The precipitate of sulphate of barium removes all the sulphuric

acid, and into the remaining clear liquor is poured a solution of pure carbonate of soda; the liquor yields a precipitate of hydrate of sesquioxide of iron evidently void of sulphuric acid. This precipitate is mixed in proper quantities with sawdust, and impure gas is allowed to pass through the mass, after which it is exposed to the air for revivification; the operation is repeated several times. If any sulphate of iron is thus generated it will be found in the resulting liquor obtained by washing the material with distilled water. M. Mallet finds by chemical analysis that the liquor contains sulphurous, but no sulphuric acid. Sulphurous acid is attributed to the presence of sulphite of ammonia contained in the gas and directly generated in the retort. In consequence of the absence of sulphuric acid, M. Mallet rejects the theory of formation of sulphate of iron in the course of revivification. He presumes that even if the presence of sulphuric acid were detected in the above-mentioned liquor, it would simply arise from the fact that sulphite of ammonia has been converted into sulphate by the absorption of oxygen during revivification. M. Mallet calls for new researches in order to completely elucidate these delicate points, and promises fresh experiments.

A. S.

On Gas Condensation. By E. Grahn.

(Journal für Gasbeleuchtung und Wasserversorgung, No. 19, 1875, pp. 705–707.)

The Author endeavours to prove by experiments that the separation of the gas products proceeds more from rest than cooling; the experiments are given not as absolutely establishing the fact, but in order to open inquiry into the subject. Tubes 8 inches in diameter and 8 feet in length were used. Tubes set horizontally, as compared with those set vertically, were found relatively useless. By comparing vertical tubes, variously arranged, the following results were found. With similar tubes, but in one of which the gas passed from bottom to top (B to T), while in the other the gas passed from top to bottom (T to B):

B to T temperature of inflowing gas 32°·5 C., outflowing 18°·9, difference 13°·6
T to B „ „ „ 31°·6 C., „ 19°·9, „ 11°·7

Nearly 2° less cooling in the latter case.

Products of condensation, mean per hour (i.):—

	T to B.	B to T.	Proportion.
Water . .	7·018 cubic inches.	16·172 cubic inches.	1 : 2·30
Tar . .	3·356 „	4·638 „	1 : 1·38
Total . .	10·374 „	20·810 „	1 : 2·00

Showing a marked difference in favour of the gas passing through the tubes from bottom to top.

The tubes were then surrounded by a steam-jacket, in order to maintain the gas at the same temperature throughout, viz. 32° to 35° C. The results were (ii.):—

	T to B.	B to T.	Proportion.
Water . .	6·713 cubic inches.	13·975 cubic inches.	1 : 2·08
Tar . . .	3·051 "	4·699 "	1 : 1·54
Total . .	9·764 "	18·674 "	1 : 1·91

The difference between experiments (i.) and (ii.) is less than 10 per cent.

The next experiment was between one vertical tube 16 feet in length, and two of 8 feet, connected together by 1-inch tubing:—

	Tar. Cubic inches.	Water. Cubic inches.	Total. Cubic inches.	Difference between inflowing and outflowing gas temperatures.
16-feet tube. . .	2·807	8 910	11·717	9°·4 C.
(a) 8-feet " . . .	2·075	8·239	10·314	9°·1 C.
(b) 8-feet " . . .	1·159	1·892	3·051	0°·3 C.
(a) and (b) together .	3·234	10·131	13·365	9°·4 C.

From these experiments it is deduced that the tubes should be a number of short ones, connected close and separately to the holder.

Experiments were also made with a holder of 18·57 cubic feet (526 litres) capacity, to determine how the gas separated at different temperatures, with the following results:—

60°·5 to 58° C.. .	14·522 cub. in. water	with 6·835 cub. in. of tar.
But after 55°·5 " 51° . .	3·478 " "	with no tar.
48° " 42° . .	1·770 " "	"
42° " 30° . .	0·549 " "	"
28°·5 " 25°·5. .	0·671 " "	"
19°·2 " 10°·5. .	0·244 " "	"
10°·5 " 9°·5. .	0·366 " "	"

Further experiments on an extended scale are contemplated.

P. H.

Lightning Conductors.

(Annales Industrielles, Sept. 19, 1875, p. 366.)

The Academy of Sciences has reconsidered its old instructions and issued new ones as to the dimensions, fixing, &c., of lightning conductors. Platinum points have been found ineffectual by the commission appointed to consider the subject, which adopts now for the summit of each conductor a pure red copper arrow of about 20 inches in length, terminating in a cone of which the angle is 15 degrees. Ball terminations are rejected. The stem is to be of wrought iron, galvanized with zinc, and not painted, the zinc being a conductor and better protector of the iron against oxidation.

Under ordinary circumstances and construction, a conductor,

it is considered, protects efficiently the volume of a cone of revolution having for its summit the point of the arrow, the height of which, multiplied by 1·75, gives the radius of the base. Thus a stem of 26·22 feet, protects a cone of which the base, measured on the ridges, will be $26 \cdot 25 \times 1 \cdot 75 = 45 \cdot 93$ feet radius. In practice these figures may be much increased; as in cases where a circuit may be established along conveniently situated ridges where conductors, metallically connected to the stem, may run uninterrupted, and end in one common underground water reservoir. All massive pieces of metal entering into the construction of the buildings should have a metallic connection with the system of conductors, and lead pipes and gutters should be properly connected with the circuit of ridge conductors by bands, as of galvanized iron, of a section of about 0·4 inch square. Compensators should be so disposed as to counteract all effects of expansion and contraction, and the conductor supports should be without isolators and as few as possible. The conductor extremities should be fixed and soldered to a large plate or cylindrical metal cross of large surface, which should dip into a reservoir of water at least 3·28 feet under ground.

W. W. B.

On the Relation between Galvanic Resistance and Motion of the Conductor. By E. Edlund.

(Poggendorff's Annalen der Physik und Chemie, No. 10, 1875, pp. 251–278.)

In the Author's "Theorie des Phénomènes électriques," he has shown theoretically that conductive resistance must be proportional to the current-strength. This conclusion is opposed to the ordinary view, according to which conductive resistance is independent of the strength of the current. Let i be the current-strength, a the section of the conductor, δ the mass of free ether in the unit volume of the conductor, and h the velocity of the ether; then $i = \delta a h$. The current-strength is thus measured by the ether mass passing through the section of the conductor in the unit of time. Let r_0 be the conductive resistance of the unit length of the conductor, according to the general view, which resistance the Author terms the principal conductive resistance; and as r is the resistance corresponding to the current-strength i, it follows that $r = r_0 i$, or eliminating i, $r = r_0 \delta a h$. According to the theory advanced by the Author, the conductive resistance is proportional to the relative velocity between the ether molecules and the molecules of the conductor. Consequently when the conductor has a velocity h, in the same direction as the ether, the resistance r is diminished, and becomes $r = r_0 \delta a (h - h_1)$. When, on the contrary, the current in the conductor has an opposite direction, the resistance increases and becomes $r = r_0 \delta a (h + h_1)$. When the current-strength becomes constant, it follows from the theory, that the electromotor power

of the circuit is equal to the sum of all the conductive resistances. Let the electromotor power and the principal conductive resistance of the circuit be respectively E and R_0; r_0 the principal resistance in the conductor, and i the current-strength, then $E = R_0 i + r_0 i$;

whence $$i = \frac{E}{R_0 + r_0}.$$

With a velocity $\pm h_1$,

$$E = R_0 i_1 + r_0 (i \mp \delta a h_1);$$

whence $$i_1 = \frac{E \pm r_0 \delta a h_1}{R_0 + r_0}.$$

The difference between both currents is consequently

$$i - i_1 = \frac{\mp r_0 \delta a h_1}{R_0 + r_0}.$$

The variation in current-strength corresponding to the motion of the conductor is thus proportional to the velocity h, and to the section a of the conductor. If the resistance R_0 is so small in comparison with r_0 that it may be neglected, variation of the current-strength and conductive resistance are independent. The Author then describes the arrangement of the apparatus by which the previous assumptions were experimentally verified. By passing an electric current through water flowing in a system of glass tubes, it was found that the galvanic resistance decreased when the conductor and the current flowed in the same direction; but, on the contrary, increased when the directions were opposed.

P. H.

On Brooks' Insulator. By M. Gaugain.

(Annales Télégraphiques, July–Aug. 1875, pp. 383–384.)

Struck with the rapid decrease of resistance in the Brooks' insulator which the Author has previously recorded, he has further continued his measurements to the end of May 1875, with the following results:—

	June 28, 1874.	Oct. 9, 1874.	May 28, 1875.
Brooks' insulator	2,269	39	26
Porcelain „	327	83	22

The measures are in millions of kilomètres. The Brooks' insulator appears to have very rapidly lost the considerable superiority it had at the commencement of the trial; but, after exposure to the air during eight months, it maintains a resistance equal, if not superior, to that of the porcelain insulator.

P. H.

Metallic Thermoscope for the Control of Night Signals.

By M. E. Hardy.

(Annales Télégraphiques, July–Aug. 1875, pp. 385–387.)

The principal difficulty in completely controlling railway night signals appears to be the very variable intensity of the light and consequently of the heat, of the lamp to be regulated. At lighting the heat is great, but decreases gradually; and in winter, after burning for sixteen hours, the lamp still gives sufficient light for the signals, but the heat is feeble. It is therefore necessary that a control apparatus should be as efficacious at high as at low temperatures, that the apparatus, while the lamp is gradually sinking, indicates extinction only at the extreme limit of the light. The Author proposes two methods. In the first, the metallic thermometer, upon which depends the control, always remains at a nearly constant temperature, and is movable around an axis placed at a certain distance from the centre of the lamp-glass. By the heat of the lamp the thermometer curves upon itself, and a spring, fixed at its extremity, gives a first contact upon an insulated screw, indicating to the watchman that the lamp is alight. If the lamp increases in heat, the spring continues to coil itself, and makes contact with a second insulated screw. A special battery, or a derivation of the control battery, then actuates an electro-magnet, the use of which is to remove the thermometer from the place it occupies above the lamp. The thermometer then cools, the second contact ceases, and the first is established. The thermometer thus executes a series of rapid movements, unless the lamp be suddenly extinguished, in which case announcement is quickly made. In the second method, two metallic thermometers are fixed upon a piece of porcelain in the chimney of the lantern above the lamp-glass. One thermometer, A, is much thinner and longer than the other, B. When the heat is great, A uncoils itself, and makes contact upon a platinum point carried by B, which coils itself in the same direction. If the temperature decreases gradually, the two thermometers uncoil themselves together, still maintaining contact; but if the light is extinguished, A, in consequence of lesser mass, uncoils more quickly than B, and contact is interrupted. A is nearer the glass than B. In use the apparatus has acted well.

P. H.

On the Application of the Tuning-Fork in Electric Telegraphy.

By Paul La Cour.

(Poggendorff's Annalen der Physik und Chemie, 1875, No. 8, pp. 628–633.)

When a vibrating body at every vibration closes and opens a galvanic circuit, the pulsations of the current become, of course,

isochronous with the vibrations of the sounding body; and when such a current, by means of an electro-magnet, is caused to affect a second sounding body tuned to unison with the first, this second body is set in vibration, whilst another vibrator of different tone has no effect upon it. The Author avails himself of this principle to transmit many signals at the same time through a single wire. A sounding-fork is caused to make contact at the sending station, so as to transmit an interrupted current from the battery to the line. The receiving apparatus consists of a tuning-fork of soft iron (tuned to unison with the sending fork), the arms or tines of which are free to vibrate each in a coil of copper wire. The intermittent current, on arrival at the station, flows through these coils, and then passes into the coils of another electro-magnet, so placed that it creates in the tines of the tuning-fork contrary magnetic poles. When the pulsations of the current are in unison with the tuning-fork, the vibrations of the latter become of such amplitude as to establish the contact of one of the tines with a contact-point, and close a local circuit. The precaution is necessary in practice to insure that the time of closing the local circuit is so small a fraction of a second as to be scarcely perceptible. The intermittent current brings only that fork into play which at the receiving station coincides with the one attached to the key at the sending station, and consequently many simple signals can be transmitted through the same wire at the same time, provided the forks are so arranged that there exists between them no simple harmonic interval.

P. H.

The Magneto-Induction Machine.

By Dr. Eduard Zetzsche.

(Dingler's Polytechnisches Journal, Band 217, part 4, Aug. 1875, pp. 257–266, 1 pl.)

The principle of these machines (von Hefner-Alteneck's system) is founded on the fact that a current is induced in a closed circuit when a portion of such circuit is introduced between a magnet whose opposite poles face each other. The direction of the induced current depends on the position of the poles with relation to the direction of the motion. The poles of a permanent steel magnet or of an electro-magnet can be employed; in the latter case, the electro-dynamic principle —discovered independently by Dr. Werner Siemens and Professor Wheatstone—comes into play. By this principle the current of the machine is itself instrumental in exciting the electro-magnetism, by adding strength to the remanent magnetism originally present in the cores of the electro-magnet. The conductor in Hefner's machine is a covered copper wire, which, for an electric-light apparatus, is wound in eight separate parts upon a german-silver cylinder, and parallel to the axis of the cylinder. The coils

entirely surround the cylinder. The exterior of the wire cylinder is partially surrounded at opposite sides, above and below, by bent iron bars, these bars inclosing about a third of the circumference of the cylinder, and being at right angles to its axis. There are as many of these bars as the length of the cylinder will admit of, and they form the cores of the electro-magnets. The bars are nowhere at a greater distance from the wire cylinder than is necessary for the latter to revolve. The two sets of bars or poles form magnetic fields of high intensity, through which the wires of the bobbin move. To combine the opposite currents, induced in the separate coils, into a current of common direction, the circumference of the cylinder is divided into eight equal parts, covered with two wires of equal length, coiled one over the other. These wires have sixteen ends, which are led through hollow pivots on the cylinder to a commutator plate that revolves with the wire cylinder. This commutator comprises eight metal sectors arranged on a plate, but separated from each other by narrow radial spaces. At two places, diametrically opposite, a metal wheel is pressed against the commutator plate by means of a strong spring. These two metal wheels form the electrical poles of the machine, and are connected to suitable terminal screws. Between these electrical poles, and joined to them by leading wires, is placed the lamp with its carbon points. From the poles flows on the one side a negative, and on the other side a positive current, always in one direction. As long as this external circuit remains open, the machine requires an impelling force scarcely exceeding that necessary to overcome friction. With a closed circuit, the quantity of electricity generated by the machine, and at the same time the work consumed by it, increase rapidly; and a small increase in the speed of revolution of the bobbin gives considerable augmentation of the current. The intensity of the magnetic field is increased—and consequently the current-intensity—by a fixed iron core placed inside the hollow wire cylinder. As this fixed position prevents the occurrence of Foucault's currents in the iron core, the machine gains, inasmuch as these currents involve unnecessary consumption of work, and give rise to heating. In smaller machines, however, in which saving of force is not so important, the advantages derived from fixing the iron core will not always outweigh the benefits of simple construction, and in such instances it is better to let the iron core revolve with the wire coils. At the same time, to reduce these Foucault currents to a minimum as far as practicable, the core should not be made of massive iron, but of coils of iron wire wound on a wooden cylinder.

There is described, besides the electric-light machine (which, at four hundred and fifty revolutions per minute, gives a light equal to that of fourteen thousand normal candles), a small machine suited for physical laboratories, which, with an internal resistance of half a Siemens unit, and at two revolutions per second, gives a current equal to that from ten Bunsen elements joined in series.

P. H.

On the Influence of Light upon the Conductivity of Crystalline Selenium. By W. SIEMENS.

(Poggendorff's Annalen der Physik und Chemie, No. 10, 1875, pp. 334–335.)

The property of crystalline selenium, first described by Willoughby Smith, and subsequently investigated by Sale of conducting electricity more readily when itself under the influence of light, than when in darkness, has been investigated by the Author. While but little affected by heat, the conductivity of crystalline selenium (or rather of a modification of crystalline selenium prepared by long heating of amorphous selenium at 210° C.), is greatly increased under the action of light; and with this modification of the crystalline condition the increase is very constant, rendering the substance a valuable means of measuring light-intensities. Dark heat rays are without direct influence on the conductivity; and heating the selenium diminishes it. Diffused daylight doubles the conductivity, and direct sunlight increases it more than tenfold. The increase of conductivity is not proportional to the light-intensity, but to a function nearly proportional to the square root of the light intensity. The application of this property to photometric purposes is promised at the conclusion of the Author's researches..

P. H.

On the Application of the Electrometer to the Measurement of Current-intensity, Polarisation, and Resistance.

By FR. FUCHS.

(Poggendorff's Annalen der Physik und Chemie, No. 9, 1875, pp. 156–169.)

Proposing that by means of an electrometer the potential difference between two points of an open or closed circuit can be determined, the Author illustrates methods of measuring current-intensity, polarisation, resistance, and electro-motive force by application and extension of known principles. In considering resistance measurements the following method is given for obtaining the internal resistance of an element. Let E be the deflection due to the potential difference of the open circuit, and s the deflection due to the tension-difference of the closed circuit of the element, s being taken when the circuit is closed through a known resistance, w, then the resistance W of the element is obtained from the following formulæ:—

$$s = \frac{w}{W + w} E; \text{ and } W = w\left(\frac{E}{s} - 1\right).$$

Thus, if for a Daniell's element $w = 1$ unit, E $16 \cdot 0$, $s = 10 \cdot 4$ divisions, then $W = \frac{16 \cdot 0}{10 \cdot 4} - 1 = 0 \cdot 54$ unit.

P. H.

INDEX

TO THE

MINUTES OF PROCEEDINGS,

1875–76.—PART I.

E 14.

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7